TAMPERE UNIVERSITY OF TECHNOLOGY

SAMI LAINE

DEVELOPING NEW DESIGN CONCEPTS FOR PASSENGER SHIPS' SAFE RETURN TO PORT -SYSTEMS

Master of Science Thesis

Examiner: Professor Jouni Mattila
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ABSTRACT

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During the last few years maritime safety has greatly increased its importance. In 2000, International Maritime Organization initiated a major development project for passenger ship safety. The work was completed and amended to SOLAS regulations (International convention of Safety of Life at Sea). The most notable reform was the addition of Safe Return to Port (SRtP) and Orderly Evacuation regulations during fire- or flooding situations.

SRtP regulations address situations where a space is considered lost or damaged because of a fire or a flooding casualty (after the fire is extinguished or flooded space is drained and/or isolated). Therefore all systems associated with the space are considered not to be in working order. In these situations, the space of casualty should be isolated from passengers and crew and checked for damages. All damaged SRtP systems capabilities should be retained and possible Safe Area use for passengers and crew should be considered. The regulations are set as design criteria, not as operating criteria. All system retaining operations must be done during a recovery time set by the operational requirements of the ship. The ship must be able to return safely to the nearest port in a pre-set time, depending on the operational requirements of the ship.

This thesis introduced the new regulations and their demands to the reader, using a built reference ship for concrete examples. The objective of the thesis was to find new design concepts for systems related to SRtP and Orderly Evacuation regulations. The concepts should be as modular as possible so that the designs could be used in different ship layout solutions.

The development process starts by presenting the current regulations and used concepts of a chosen reference ship. The used reference ship is designed and built in Rauma shipyard and partially fulfils the SRtP requirements. These reference system concepts were analyzed, as well as the interpretations of the regulations and the ship's operating procedures. Testing and support for the systems were also included in the review.

The analysis showed that the ship's operating procedures and current system designs did not meet in a desired way - despite the fact that the demands set by regulations were met. It also showed that interpretations themselves contained obscurities. Based on the analysis, propulsion-, fuel oil-, fire main-, sprinkler-, bilge- and flooding systems were subjected to detailed development process. The ship's flooding system was used as an example for practical financial calculations.

It was found out that all systems could be improved with different design concepts – most of them possessing modular qualities. Fuel oil system's future concepts rely heavily on environmental reforms. Also, a ships overall readiness for emergency situations could be improved by system integration, better operating procedures and sufficient training by the owners and shipyard.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Automaatiotekniikan koulutusohjelma
LAINE, SAMI: Uusien suunnittelumallien kehittäminen matkustajalaivojen Safe Return to Port -järjestelmille
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Turvallisuudesta on tullut tärkeä osa telakkateollisuuden suunnittelua. Vuonna 2000 Kansainvälinen merenkulkujärjestö uudisti laajamittaisesti säännöksiään koskien matkustajien turvallisuutta matkustaja-aluksilla. Uudistuksista merkittävimpiä ovat matkustaja-alusten Safe Return to Port- ja Orderly Evacuation säännökset, jotka takaavat laivojen turvallisuuden palo- ja vuototilanteissa sekä mahdollistavat rauhallisen evakuoinnin tarvittaessa.

SRtP säännöksillä pyritään vaikuttamaan tilanteisiin, jossa laivan jokin tila on altistunut tulipalo- tai vuototilanteelle (sen jälkeen kun tilan palo on sammutettu tai vuoto eristetty/tyhjennetty). Näin järjestelmän osat, jotka liittyvät jotenkin tilaan, oletetaan menetetyiksi. Tällaisissa tapauksissa vahingoittunut tila tulee eristää matkustajilta ja henkilöstöltä. Lisäksi tulee suorittaa tarkistus vahinkojen laajuudesta. Kaikki SRtP säännöstön määrittelemät järjestelmät tulee palauttaa toimintakykyisiksi laivan vahingoittumattomissa tiloissa, ja mahdollisten turva-alueiden käyttöä tulisi harkita vahinkolaajuuden mukaan. Nämä toiminnot tulee suorittaa tietyssä palautumisajassa, joka riippuu laivan toiminnallisista vaatimuksista. Laivan tulee päästä turvallisesti lähimpään satamaan ennalta määrätyssä ajassa, riippuen myös toiminnallisista vaatimuksista. Säännökset ovat määrittelyjä suunnittelulle, eivät laivan operoinnille.

Tämä diplomityö esittelee uudet säännökset ja niiden asettamat vaatimukset lukijalle käyttäen apuna jo valmistunutta referenssilaivaa. Työn tavoitteena oli löytää uusia malleja SRtP (Safe Return to Port) ja evakuointi säännöksiin liittyvissä järjestelmissä. Suunnittelukonseptien tavoitteena on riittävä modulaarisuus, jotta niitä voitaisiin käyttää erilaisissa matkustaja-aluksien ratkaisuissa.

Työssä esitellään aluksi vallitsevat säännökset ja referenssilaivassa käytetyt ratkaisut. Referenssilaivana käytetään Rauman telakalla rakennettua alusta, joka jo osittain täyttää SRtP vaatimukset. Nämä mallilaivan ratkaisut, sekä laivan hätätilanne proseduurit, analysoitiin kehityskohteiden löytämiseksi. Lisäksi sääntöjen tulkinnat itsessään analysoitiin mahdollisia parannusehdotuksia varten. Katsauksessa otettiin huomioon myös mahdolliset tarpeet testausta ja teknillistä tukea ajatellen.

Analysoinnin tulokset osoittivat, että operointimenetelmät ja käytetyt ratkaisumallit eivät kohdanneet halutulla tavalla, vaikkakin sääntöjen asettamat vaatimukset täyttyivät. Lisäksi todettiin, että sääntöjen tulkinnoissa löytyy kehitettävää jos halutaan löytää toimivia kokonaisratkaisuja. Analysoinnin perusteella propulsio-, polttoaineensyöttö-, palosammutus-, sprinkleri-, pilssi- sekä vuotojärjestelmä valittiin lähempää tarkastelua

varten. Vuotojärjestelmä valittiin konkreettiseksi esimerkiksi, jonka uuden ja vanhan ratkaisun välillä suoritettiin myös taloudelliset arviot.

Kehitystyön tuloksena järjestelmille löydettiin uusia, modulaarisia ominaisuuksia sisältäviä, ratkaisumalleja. Polttoaineensyötön mahdolliset ratkaisut ovat riippuvaisia tulevaisuuden ympäristömääräyksistä. Lisäksi huomattiin, että alusten kokonaisvaltaista valmiutta hätätilanteita varten pystyttäisiin parantamaan systeemi-integraation, parempien operointimenetelmien ja riittävän koulutuksen avulla.

PREFACE

The topic for this Master of Science thesis was provided by STX Finland AS (Rauma shipyard). The shipyard also provided all the needed materials regarding the reference vessel, and a productive working environment for the writing process. The examiner for this thesis was Professor Jouni Mattila from Tampere University of Technology. The work was supervised by Machinery Design Manager, Mr. Reijo Lehtola of STX Finland AS.

I would like to thank both Jouni and Reijo for all the advice and support they have given me during this writing process. My sincere thanks to Mr. Tonny Bakker (Project coordinator – Machinery Design) and Mr. Pekka Lehtonen (Project Coordinator - Electrical Design) of STX Finland AS for all the help they gave me during this process. All of the countless talks and brainstorming sessions were not only crucial for the work but also enjoyable and full of enthusiasm.

I also want to express my gratitude towards all the designers in STX who participated in this project. I am also very grateful for Mr. Vince L. Todd, Chief Engineer Officer of P&O Ferries, for giving invaluable information from the perspective of the ship's operators.

Last, but definitely not the least, the most sincere thank you to my family for their ever-present love and support.

Tampere, October 2011

Sami Laine

CONTENTS

ABBREVIATIONS AND MARKINGS

Class	Classification society: a body, exercising technical supervision over shipbuilding and navigation, and establishing technical and safety standards to ensure the seaworthiness of vessels.
CP-propeller	Controllable Pitch Propeller.
Critical system	Systems identified in the overall assessment process to have a possibility to fail to operate adequately as a result of a fire or flooding casualty.
DDS	Data Distribution Service.
ECR	Engine Control Room.
ECDIS	Electronic Chart Display and Information System.
ERP	Enterprise Level.
Essential system	All systems, or sections of systems, in spaces not directly affected by a flooding or fire casualty that need to remain operational according to SOLAS regulations.
FMEA	Failure Mode Effect Analysis.
GMDSS	Global Maritime Distress Safety System.
HFO	Heavy Fuel Oil.
HMI	Human Machine Interface.
IAS	Integrated Automation System.
IMO	International Maritime Organization.
LAN	Local Area Network.
LNG	Liquefied Natural Gas.
MAL	Management Level.
MDO	Marine Diesel Oil.
MGO	Marine Gas Oil.
MSC	Maritime Safety Committee.
OSI	Open System Interconnection.
PA	Public Address.
PCS	Process Control System.
PLC	Programmable Logic Controller.
RoRo	Roll On/Roll Off.
RSP	Redundant Steering Position.
RTU	Remote Terminal Unit.
SCADA	Supervisory Control and Data Acquisition.
SE	Systems Engineering.
SOLAS	A maritime treaty for Safety of Life at Sea. A set of regulations for maritime safety of vessels.
SOS	System of Systems
SOSE	System of Systems Engineering.

SRtP	Safe Return to Port.
UHF	Ultra High Frequency.
UPS	Uninterrupted Power Supply.
VMC	Ventilation Motor Control.

1 INTRODUCTION

Safety is a concept which has greatly increased its meaning in all current fields of industry. After the famous accident of *RMS Titanic*, passenger safety has become a major priority in marine industry. Since 1914, the onboard safety of ships has been improved with international treaties – most notably the International Convention for Safety of Life at Sea (SOLAS). During the years, this treaty has been developed with constant amendments until the founding of the United Nations and the establishment of International Maritime Organization (IMO). Since 1948 IMO has been the governing body for safety on seas with constantly updated regulations of SOLAS acting as its foundations. These regulations are followed by all 170 Member and Associate States. The safety regulations cover the whole life cycle of a ship, from designing phase through operational requirements to releasing the ship.

One of IMO's committees, Maritime Safety Committee (MSC), went through a major development project of updating the safety regulations for passenger ships. In 2006, in the 82nd session of the MSC, a revised package of amendments to current regulations was agreed – most notably regulations of Safe Return to Port (SRtP). The aim of these regulations was to switch the emphasis more on preventing casualties from occurring, and to enhance the survivability of the ships. These regulations came to force in 1 July 2010.

SRtP regulations were developed to improve passenger safety in fire or flooding casualties during sea voyages. SRtP approach deals with situations where any given space of the ship is damaged because of a fire or a flooding scenario. Hence, all systems associated with that space are considered to be out of order. In these types of scenarios, the space should be isolated from all seagoing persons and checked for possible damages. All damaged systems capabilities, under the scope of SRtP regulations, must be retained; and Safe Areas should be used if there is any threat directly towards passengers or crew. The regulations are set as design criteria but do not suggest any operating criteria for the ship's personnel. This is left entirely up to the owner and operators of the ship. All operations retaining system capabilities must be done during a recovery time set by the operational requirements of the ship. The ship's features must enable a safe return to the nearest port in a pre-set time, under certain weather criteria and minimum speed - depending on the operational requirements of the ship.

1.1 Objective of the thesis

The main aim for this thesis is to find new design patterns, concepts and possible modularity for different systems operating in passenger ships, under the new SRtP regulations for car passenger ferries, through systems engineering process – especially SRtP systems with a possibility for automated and/or remote controlled features.

As technology develops rapidly and demands for safety onboard through regulations become even stricter, STX Finland AS (Rauma shipyard) continues to pursuit more efficient, customer friendly, concepts for safety related systems, and to explore the use of automation as a means for more operator friendly solutions. This thesis will try to further develop the SRtP process and system designs used in the shipyard - approaching problems more from the user's point-of-view but keeping in mind the economical and technical realities faced by the designers. Also, as the SRtP regulations are new and yet hardly in use, one objective is to raise questions and promote new ideas for further development and standardization of the rules and their interpretations.

1.2 Thesis structure

The development process is carried out by examining the new regulations and existing applications in a chosen reference vessel according to systems engineering (SE) and system of systems engineering (SOSE) methods. The regulations, used interpretations and all needed background information regarding the SRtP process are presented in chapter 2. In chapters 3 and 4, the SRtP systems of the reference vessel are introduced. These chapters also describe the current concepts used for each system to fulfill the SRtP requirements. The ship's capabilities in SRtP situations are analyzed, as a single entity and system by system. The systems are analyzed based on new interpretations of the regulations and certain criteria to determine which of the systems could be further developed. The analyzing process is explained in chapter 5. These systems are exposed to SE process and the ship as a whole to SOSE process. User requirements and feedback are gathered by interviewing the operators of the reference vessel. The new concept ideas are introduced in chapter 6. Conclusions of the whole process and recommendations for further work are presented in chapter 7.

1.3 Reference vessel

A reference vessel is chosen for concrete examples, figures and specific ship layout. The reference vessel partially complies with the SRtP regulations (flooding scenarios are excluded and some demands have been lowered). The ship is called *Spirit of Britain* and it is a RoRo-passenger (Roll on/Roll off) ferry operating between Dover and Calais. It was built in the STX Finland AS (Rauma shipyard) and was delivered on 5 January 2011. The vessel is intended for 2200 seagoing persons and dedicated cargo, mainly different types of vehicles. The ship is approximately 213 meters long, 31 meters in breadth and its draught is 6.5 meters. Tonnage is 49 000 tons. The ship has two shaft lines with CP-propellers (Controllable Pitch Propellers), both lines operated by two heavy fuel oil main engines. Four auxiliary engines supply the electric network of the vessel. Maximum speed of the vessel is 22.0 knots. [1]

The ship’s centralized automation system, IAS (Integrated Automation System), is designed to comply with the regulations of an unattended engine room. That is to say that all normally conditioned machinery operations, requiring attendance at frequency of less than 24 hours, are covered by an unmanned automation system. All control systems and functions for continuous remote and/or automatic control are provided with proven redundancy. All alarms and most of the monitoring and control functions are handled by IAS. Ship’s individual systems may possess their own automation systems which connected to IAS. The system includes 3050 I/O points and additional 10% as spare points with several serial line interfaces to other systems. A fully automated power management system for four diesel generators and four shaft generators works as part of IAS. [2]

The basic architecture for IAS cabinet layout and cabling is shown in figure 1.1 (Appendix 1).

1.4 System design process

Systems, and their features, discussed in this thesis are approached from two separate perspectives; through SE or through SOSE. Both approaches are used. Ship’s features can be divided into single systems which combined together, and with the personnel of the ship, comprise a more complex meta-system. This system of systems needs to be approached differently than any single system. SE is used to find new designs and concepts for single systems, SOSE when the operations of the whole ship - its capabilities and personnel - are examined.

1.4.1 Systems engineering

SE can be described as an interdisciplinary field of engineering. The purpose of SE is to find new ways to design and manage difficult engineering projects. Normally, SE should cover the whole life cycle of the project, from designing to implementation and testing, even recycling.

A system is generally thought to be a synonym for a product. According to Stevens, instead of solely focusing on the end product we should examine the full operational capability of a system, providing the user with all the necessary services and not just the end product [3]. The end product is a valuable part of a system but operational procedures, support processes and possible training must be integrated into the design process. Stevens states this as an operational environment, consisting of multiple external systems interacting with the product – consisting of cooperating or competing systems [3]. Development environment is needed to produce a convincing operational environment and a quality end product (figure 1.2). A development environment consists of development support systems, such as infrastructure, test and verification systems.

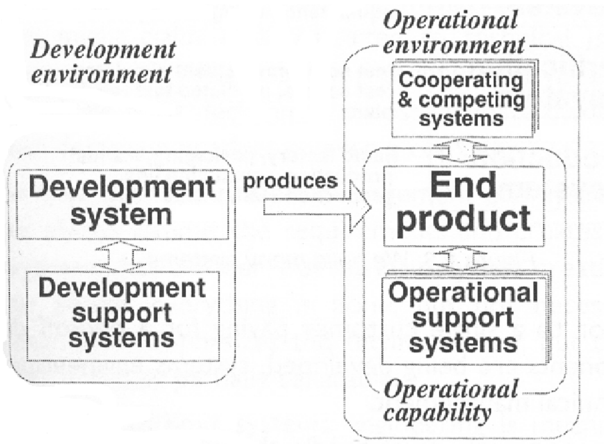

Figure 1.2. *Development and operational environment [3]*

Operational environment is considered to be the complete ending of a system's life cycle. The cycle starts from user requirements and follows a sequential development process consisting of system requirements, architectural design and testing of integration, installation and operations. According to Stevens, feedback and testing between these stages are important milestones for the quality of the system. When information is produces in this order, it will ensure that users, developers and designers have all the data that they require for a successful product. This will also guarantee that all components of the design process are thought to be part of a larger entity and are more easily integrated into a complete system. [3.]

A system engineer is in charge of the process during the whole life cycle, from abstract stages in the beginning through detailed implementations. System engineer should balance all competing factors (risk, cost, performance) while ensuring that user requirement demands and practicality remain a high priority. It is easier to comprehend a small simple system as a single entity instead of larger, more complex, one. Stevens claims that, for larger systems, overall behavior emerges only when the complete system can be seen as a single entity [3]. As so, the sequential development process is invalid when dealing with large-scale systems. In these cases, when sequential development process cannot be used due to system complexity or magnitude, SOSE approach becomes valid.

Figure 1.3 shows the role of SE in a system's life cycle process until a practical compromise is reached. The objective is to have a compatible set of user and system requirements, design, cost and practicality before implementing a system [3].

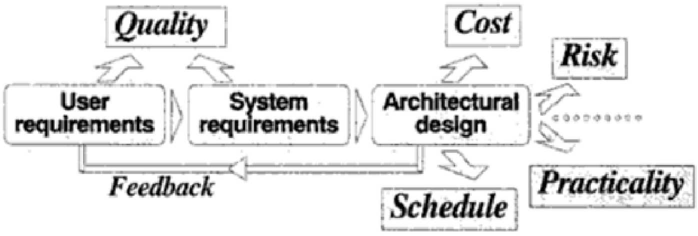

Figure 1.3. *Role for SE [3].*

In this thesis, the whole system life cycle will not be examined thoroughly. The partial examination will focus more on user and system requirements, architectural design and practicality. Costs and quality will be acknowledged in the design process but cannot be realistically estimated - only one system is chosen as a concrete example for economical calculations. Feedback is gathered from system designers and from the operators of the reference vessel. To provide a competent operational environment, the testing and support of the systems are also analyzed.

1.4.2 System of Systems Engineering

The term system of systems engineering is relatively new, although the study of complex systems as a domain is far older. System of systems (SOS) type problems were already studied in mid 1900s and complex interactions between system dates back even further [4.]. In this thesis, the definition for SOSE covers the following aspects [4, see 5]:

- SOS involves integration of multiple, independent, systems into a meta-system
- SOS generates capabilities beyond any constituent systems working independently
- integration into a SOS may cause some constrain for previously independent systems
- SOS performs tasks where separate systems are an integral part but could not accomplish the tasks as independent systems

Current SOSE development can be divided into two separate paths: technical and inquiry – shown in Table 1.4. The technical path studies systems from a technically dominated perspective, dealing with interoperability, information technology, net-centricity, integration etcetera. Technical perspective aims for an integrated product and is closely related to SE. The inquiry path is more related to 'soft systems' thinking, concerned with human/social, contextual and high level inquiry to complex system problems. [4]

Table 1.4. *Bifurcation in SOSE field development [4].*

Attribute	SOSE field development paths	
	SOSE (Technical)	SOSE (Inquiry)
Primary focus	Technical product	Inquiry processes
Result of effort	Hardware / software solution	Purposeful response
Driving paradigm	Hard systems	Soft systems
Foreground approach	Systematic	Systemic
Background approach	Systemic	Systematic
Results acceptance	Objective	Interpretative
Closest related field perspective	Systems engineering	Systems thinking

Even though the bifurcation presents an opportunity for multiple perspectives, SOSE must evolve into one methodology according to Souza-Poza [4]. This way all aspects are taken into consideration and all synergies can be utilized. This thesis will use SOSE concept when applying new rules and concepts that concern the vessel as a single entity. SOSE method will be the basis for a meta-system that is the whole ship, consisting of independent systems and the personnel using them. The aim is to ensure that all new requirements by authorities and operators are met in safe, practical, economical and user-friendly way. This is done by using as much of already existing features as possible, creating new synergies and ensuring that the ship is equipped to handle all emergency situations.

2 RULES AND REGULATIONS

Shipbuilding is an industry where most operations are largely defined and scrutinized by different set of rules and regulations, mostly aiming to enhance maritime safety, efficiency of navigation, and prevention and control of marine pollution of ships. The basic rules, regulations and standards for shipbuilding are set on an international level by IMO. These and other optional or additional regulations are enforced over a vessel by a flag state: a vessel is registered under a flag state which is responsible for the vessel's official inspections, certificates, and documents. The vessel also operates under the admiralty laws of the state. From here on, the Government of the State whose flag the ships is entitled to fly is addressed as Administration. Normally Administration authorizes a non-governmental Classification Society (Class) to oversee that the interpretations of the rules, regulations and standards during the construction phase of the vessel are followed. [6]

The regulations are presented to the reader for background information, and to understand what sort of requirements the new regulations place on system design.

2.1 SOLAS

On 1 November 1974 IMO convened The International Convention for the Safety of Life at Sea. The SOLAS convention is widely regarded as the most important treaty for maritime safety. SOLAS regulations were entered into force on 25 May 1980 and have been regularly updated since: twice by means of protocol (1978 SOLAS protocol and 1988 SOLAS protocol) and numerous amendments by means of resolutions – mostly by MSC. [6.] Updates are necessary keeping up with the rapid development of technology and the increasing problems with maritime pollution.

SOLAS regulations define different standards and rules for shipbuilding. The aim of these rules is to standardize different vessels and systems so that they meet the increasing requirements for passenger safety, environmental issues, and demands for carriage of cargoes and dangerous goods. All SOLAS regulations do not apply to every single type of vessel. Depending on the type, certain regulations have to be put into force. Only Chapter V (Safety of Navigation) of the SOLAS regulations applies to all vessels - except warships, naval auxiliaries and other non-commercial ships owned and operated by the Contracting Government. [6]

SOLAS regulations define a passenger ship as follows: "A passenger ship is a ship which carries more than twelve passengers." [6, p.15] A car passenger ferry is therefore classified as *a passenger ship* and complies with the regulations for a passenger ship. [6.]

2.2 Safe Return to Port

Safe Return to Port ideology is based on the regulations 8-1, Chapter II-1 of SOLAS and regulation 21, Chapter II-2 of SOLAS. Chapter II-1 consists of regulations for construction of structure, subdivision and stability, machinery and electric installations. Chapter II-2 of SOLAS consists of regulations for construction of fire protection, fire detection and fire extinction. These regulations were amended to SOLAS in 2006 by the MSC of IMO and are part of the resolution MSC.216(82) (annex 2 and 3). [6; 7; 8]

The regulations are applied according to the following instruction: "Passenger ships constructed on or after 1 July 2010 having a length, as defined in regulation II-1/2.5, of 120 m or more or having three or more main vertical zones shall comply with the provisions of this regulation." [7, p.49; p.79]

The purpose of the regulation 21 is to establish design criteria for a ship's safe return to port with its own propulsion system after a fire casualty which does not exceed casualty threshold. Regulation 8-1 sets the same requirements in case of flooding in watertight compartments. Also, the ship must provide a safe area for passengers which fulfills the functional requirements and performance standards described in the regulation. A casualty threshold includes a loss of space of fire origin up to the nearest "A" class boundary (either part of the space of fire origin or spaces next to it) if the space is protected by a fixed fire-extinguishing system; or a loss of the space of fire origin and adjacent spaces up to the nearest "A" class boundaries which are not part of the space of fire origin if it is not protected by a fixed fire-extinguishing system [8]. "A" class boundary is formed by either bulkheads and/or decks constructed of steel (or other equivalent material), which are suitably stiffened, insulated with approved non-combustible materials, do not allow the passage of smoke and flames (to the end of one-hour standard fire test) and are approved by the Class [6; 7].

An example of layout for spaces of fire origin is presented in figure 2.1. "A" class boundaries are marked with red line color and spaces of fire origins are numbered for scenario listing (numbering is arranged by: deck - main fire zone - running space number).

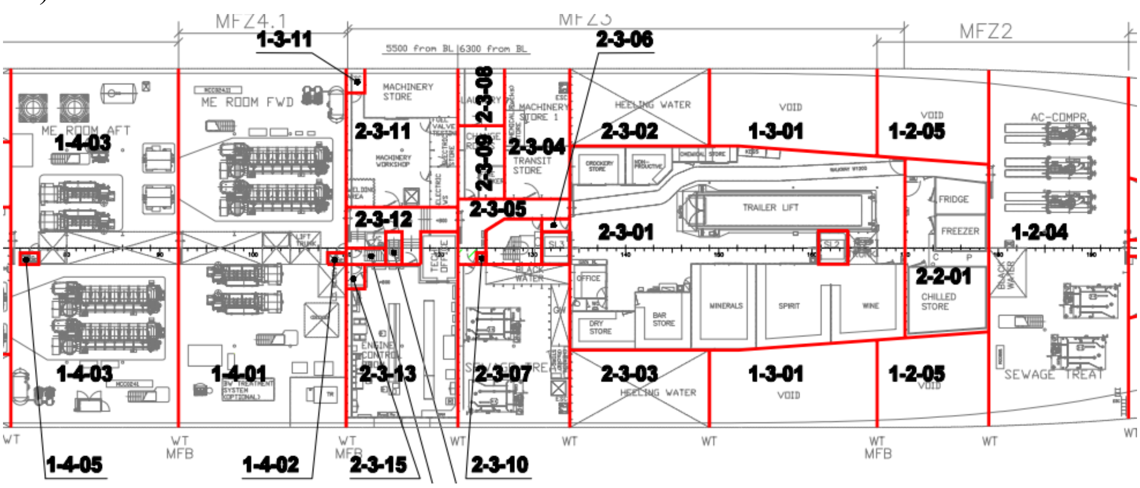

Figure 2.1. *"A" class boundaries and spaces of fire origin [9.]*

In order to be deemed capable of returning to port safely, the following systems must remain operational after a fire casualty (Regulation 21) and/or when the ship is subject to flooding in any watertight compartment (Regulation 8-1) [7; 8]:

- Propulsion system
- Steering and steering control systems
- Navigational systems
- Systems for fill, transfer and service of fuel oil
- Internal communications system
- External communications system
- Fire main system
- Fixed fire-extinguishing systems
- Fire and smoke detection system
- Bilge and ballast systems
- Power-operated watertight doors
- Systems intended to support Safe Areas
- Flooding detection system
- Other systems determined by the Administration to be vital to damage control efforts

Generally, production and distribution of electric power as well as the automation system(s) of the ship are included to the list.

As described above, Safe Area(s) are to be provided in SRtP situations. A Safe Area(s) should be an internal space(s); however, the use of external spaces can be allowed with the agreement of the Class. Sanitation, water, food, medical care, shelter, means of preventing heat stress and hypothermia, light and ventilation have to be arranged for the passengers and crew members. Ventilation must be designed in a way which reduces the risk of smoke and hot gases entering the Safe Area. There must be means of access to life-saving appliances from the Safe Area(s), taking into account the possibility of a loss of a complete vertical fire zone. [7; 8]

A SRtP mode in a ship refers to a situation where a space is considered lost or damaged because of a fire or a flooding casualty (after the fire is extinguished or flooded space is drained/isolated). Therefore all systems associated with the space are considered not to be in working order – in worst the case scenario. When a ship is in SRtP mode, the space of casualty should be isolated from passengers and crew and checked for damages. All damaged SRtP systems capabilities should be retained and possible Safe Area use for passengers and crew should be considered - depending on the scenario. The use of Safe Areas in SRtP situations is not clearly stated in the rules, as regulations are set as design criteria of the ship – not as operating criteria. All operations must be done during a recovery time set by the operational requirements of the ship (recovery time for the reference vessel is two hours). The ship must be able to return safely to the nearest port in a pre-set time, also depending on the operational requirements of the ship.

2.3 Orderly evacuation

Regulation 22, Chapter II-2 of SOLAS further complements the SRtP ideology and regulations. The rule is applied as described for regulations 8-1 and 21 in the previous paragraph. The regulation deals with fire scenarios where the casualty threshold is exceeded, meaning a loss of an entire vertical fire zone or main fire zone. In these situations the regulation states that the following systems must remain operational to support orderly evacuation and abandonment of the ship [7; 8]:

- Fire main system
- Internal communications systems
- External communications system
- Bilge and ballast systems
- Emergency lighting (escape routes, assembly stations, embarkation stations)
- Guidance systems for evacuation

Production and distribution of electric power is needed to guarantee the operation of the above listed systems. Therefore, in most vessel types, systems for fill, transfer and service of fuel oil are required to be in working order.

The above systems must remain capable of operation for at least 3 hours (assumed that that other parts of the ship are not affected by fire). These systems are not required to remain operational within the damaged areas. [7; 8]

2.4 Safety Centre

SRtP and orderly evacuation regulations are designed to improve the technical aspects of the ship for passenger safety, whereas the Safety Centre is more of a concept designed to assist with the management in emergency situations. Regulation 23, Chapter II-2 of SOLAS states that all passenger ships constructed after 1 July 2010 must have on board a Safety Centre [7; 8].

The Safety Centre must be a space, part of the navigation bridge or a separate adjacent space next to it (with direct access to the bridge). This is to ensure that the management process can be performed without distracting watch officers from their navigational duties. The centre must have means of communication to the central control station, navigation bridge (if not part of it), the engine control room, the storage room(s) (for fire-extinguishing system(s)) and fire equipment lockers. [7; 8]

The Safety Centre must provide full functionality (operation, control, monitoring or potential combination of the previous three) of the following safety systems – despite possible requirements set elsewhere:

- Powered ventilation systems
- Fire doors
- General emergency alarm system
- Public address system
- Evacuation guidance system
- Watertight (and semi-watertight) doors
- Indication of shell doors, loading doors and other closing appliances
- Water leakage of bow doors, stern doors and any other shell door
- Television surveillance system
- Fire detection and alarm system
- Fixed fire-fighting local application system(s)
- Sprinkler and equivalent systems
- Water-based fire-extinguishing systems for machinery spaces
- Alarm to summon crew
- Atrium smoke extraction system
- Flooding detection system
- Fire pumps and emergency fire pumps

The Safety Centre does not have to be considered part of the SRtP ideology, that is to say, it does not have to be in working order in all flooding or fire casualty scenarios of the ship. In SRtP sense, it is not redundant.

2.5 Interim explanatory notes

In shipbuilding the standards, regulations and rules for construction of a vessel are not absolute. There are always at least three different points-of-view to be considered: shipyard, Class and the owner of the ship. Although the regulations are to be followed as set, there is always room for interpretations. As a result, there is constant dialogue between the shipyard, owner and the Class. Therefore IMO publishes interim explanatory notes for new regulations, and updates them regularly as they evolve with design and construction experience.

In this thesis, interpretations for regulations 8-1 of chapter II-1 and 22, 23 of chapter II-2 are followed according to IMO's recommendations demonstrated in Circulation.1369, approved in the 87th session of Maritime Safety Committee in London (from 12 to 21 May 2010). The interpretations aim to clarify the regulations in a way where there is less room for speculation and that all parties involved know the boundaries within they can act. The explanatory notes are intended to outline the process of verification and approval of a ship's design, and to describe the necessary documentation required when SRtP regulations are applied. Also, explanatory notes give detailed design criteria for designers on what is acceptable and what is not – for example when pipes or cables are considered lost, when fire insulation is needed etcetera.

Design process of SRtP systems should include a written description of all of the systems to be installed and all the information how to achieve systems' capabilities and functionality after a casualty. Starting point for the assessment process is that the operating patterns (maximum area of operation and/or routes, maximum number of passengers and crew, type of vessel and so forth) have been defined by the owner. All of the system capabilities build into the ship will depend on the operating patterns. [10]

The design process should be carried out in a way that the following information is acquired, documented and delivered to the Class and the owner: ship's description and assessment of ship's capabilities; including overall assessment of essential systems and detailed assessment for critical systems. Ship's description must contain information on the design criteria for essential systems, the basic layout of the vessel, criteria for the selection of Safe Areas, list of essential systems intended for assessment process, design documentation for essential systems, data regarding the minimum speed versus weather and sea conditions, and any additional information considered important for design. The operating patterns should be included in the ship's description. The basic layout may include information on compartment boundaries, general arrangement plan, capacity plan, watertight subdivision plan, structural fire protection plan and plan of spaces protected by fixed fire-extinguishing systems. [10]

Assessment of ship's capabilities should be performed by the process shown in figure 2.2 (Appendix 2). The assessment should be based on structured methods and should document the intended essential systems' functionality after a casualty scenario. The SOLAS regulations do not determine any quantities or performance limits; therefore ship's ability to return to port safely is linked only to the operating patterns. The capability of each system in a worst case scenario should be presented in the on board documentation.

When the overall assessment process is concluded, results define the need for possible detailed assessment process for critical systems. That is to say, if no critical systems were found during the overall assessment, the overall assessment can be considered acceptable without the need for a detailed analysis. However, if critical systems were found, a detailed assessment of any critical system is needed. Detailed assessment should supplement the ship's description by giving details on power supply, pipes, cables, devices and connections of the system. Details of possible manual actions must be included, as well as details of any operational solution forming part of the design criteria. Additional information can be included in form of quantitative analysis (for example fire risk within a space), FMEA (Failure Mode Effect Analysis) or analysis regarding consequences of flooding within a space. [10]

All above mentioned information must be documented for approval and for on board documentation. Additional information is needed for test programs and maintenance plan. Record of ship systems' capabilities should be added to the list of operational limitations for ship's safety management manual. [10]

3 SRTP SYSTEMS

Feedback from the operators suggests that SRtP systems could be further developed from an operator's point-of-view [11]. At the same time, the costs for new concepts and models should be kept in tolerable level. The aim is to give a possible buyer economically competitive, yet quality, concepts to choose from - while ensuring that the system costs do not go up excessively due to the SRtP regulations.

For this reason, SRtP systems' capabilities and requirements should be assessed. Some systems could be used for more accurate decision making, some actions could be avoided or perhaps economically remote controlled. Even the SRtP regulations and interpretations themselves could be improved or they might require clarification or modifications. First, the SRtP systems must be examined and explained. This is done by examining the used concepts in the reference vessel. This determines the system requirements placed by the SRtP rules.

After the systems have been introduced to the reader, they are analyzed for potential further development. Same analysis will be carried out for dominant regulations and interpretations. This is done by using feedback from the owners and the personnel of the shipyard, as well as estimating future trends for SRtP development of systems. This determines the user requirements for SE, and provides a platform for better quality of the product.

3.1 Propulsion system

Propulsion system can be considered as one of the hardest, and most complex, systems to deal with regarding SRtP regulations. Propulsion system is dependent on other systems to work properly and this must be taken into consideration. In our reference ship, the basic principle has been the use of two shaft lines, both supported by two main engines (four in total), placed in separate main engine rooms – each engine room assigned to serve only one shaft line. In any casualty scenario, one complete shaft line (and its auxiliary systems) should stay operational. The port side shaft line passes through the after main engine room and is enclosed in “A” class trunk to retain its capabilities in after main engine room casualty scenarios.

A propulsion shaft line is directly connected to the following systems: shaft generator, reduction gear, shaft bearings, stern tube and its lubrication system, CP-propeller system, fresh- and sea water cooling systems, lubrication oil system, compressed air system and main engine room ventilation. These systems are equipped with different SRtP features to preserve shaft line operability in SRtP situations. Also, functional fuel oil system is required which will be examined in paragraph 5.4. Main engines and their auxiliary systems are already well supervised and controlled. Main engines have their own supplier delivered automation system, connected to IAS for alarm indications and control. Most auxiliary systems are supervised and controlled by IAS. Automatic operations should be avoided as propulsion power should not be exposed to errors or malfunctions. Most of the manual actions are related to compressed air system and water cooling system isolations.

Currently, there are four interpretations for propulsion system (interpretations 17-20). Interpretation 18 states that, in a SRtP situation, the ship must maintain a minimum speed of 6 knots for sufficient time while heading into Beaufort 8 weather and corresponding sea conditions [10]. Interpretation 19 explains the survival of the shaft line in flooding or fire situations. The shaft line and relevant bearings must be either enclosed in an "A" class tunnel or it must be proved that it can operate under water and is protected by a dedicated water spray system to survive a fire/flooding casualty [10]. Interpretation 20 approves the use of local controls if adequate communications and emergency lightings are arranged [10].

3.2 Steering and steering control systems

The principle of steering system, in *Spirit of Britain*, resembles the propulsion system's model. There are two separate, hydraulic operated, rudders – located at the after port- and starboard side of the ship. Hydraulic power packs are located in assigned steering gear rooms with other essential machinery. The power supplies for steering machineries are duplicated from main- and emergency switchboard. Control and indication of both rudders are arranged to three locations: bridge, redundant steering position (RSP) or locally. This means that in any casualty scenario at least one rudder is operational from one of the three operating locations. As with propulsion systems, the system for steering does not require a lot of actions, and automatic operations should be avoided.

Interpretation 20 approves the use of local controls (when adequate communication and emergency lighting are arranged) and the use of alternative means for steering, such as azimuth thrusters, pump jets, rudders, propellers but the use of tunnel thrusters should not be considered [10].

3.3 Navigational systems

The navigational systems in SRtP sense contain various systems from simple gadgets to more advanced systems. In the reference vessel, the redundancy is secured in two different ways: with RSP, situated at the top of the ship, with access to redundant fixed systems; and with portable units. Table 3.1. shows all navigational systems and how redundancy is arranged.

Table 3.1. *Navigational systems [12].*

Requirement	Item		Portable unit	Fixed system
Available in another location	a)	barograph	X	-
		hand wind speed meter	X	-
		device to receive weather forecast maps	-	X
	b)	compass and bearing repeater	-	X
	c)	nautical charts and publications or ECDIS	X	-
	d)	receiver for global navigation satellite system	-	X
	e)	rudder, propeller thrust and pitch indicators	-	X
	f)	9 GHz radar	-	X
	g)	automatic identification system	-	X
Should remain operational	a)	whistle	-	X
	b)	navigation lights	-	X
	c)	daylight signal lamp	X	-

The location for RSP is determined by the contract specification and is not influenced by any SRtP related regulation or interpretation. As so, the RSP could be placed anywhere on the ship.

The fixed systems are divided into two categories: navigational equipment and signaling systems. Signaling systems should remain operational at all times, whereas navigational equipment must be available after a SRtP scenario.

Device to receive weather forecast maps is provided via ship's VSAT satellite communication. The redundancy is arranged by using a Fleet33 back-up antenna, not part of any casualty scenario, as the primary antenna. The compass and bearing repeater is provided by two gyro compasses with a redundant signal to RSP. Also, there is a magnetic compass on an open deck - not part of any casualty scenario or dependent on external power supply. Global navigation satellite- and automatic identification systems use a DGPS satellite signal in normal use. There is a back-up system in RSP with a dedicated GPS antenna when the primary signal cannot be used. The radar system is arranged as to use X-band radar scanner signal at the bridge as a primary option. A manual changeover for the signal is provided in RSP if the equipment at the bridge is damaged. Also, the bow X-band scanner can be used as a secondary unit.

Whistle system uses an electronic whistle as a primary unit and a pneumatic operated typhoon as secondary unit. The typhoon is connected to the ship's working air system and has one dedicated isolation valve. The navigation and signal lights are divided into two independent power- and distribution networks. The primary control station is located at the bridge, the secondary unit in RSP. System cabling is designed in a way that either lighting network is in working order at all times.

As described above, many of the navigational systems do not require manual actions in the conventional sense. Most "actions" are simply switching on secondary equipment, using back-up systems or –signals. In *Spirit of Britain* the RSP contains all navigational back-up systems. According to regulations and interpretations, all of the fixed systems in table 3.1 should be considered as SRtP navigational systems. In addition, most ships build in Rauma shipyard will be equipped with an ECDIS (Electronic Chart Display and Information System) which should also be considered as part of SRtP systems. Additional systems are possible but dependable of contract specifications.

3.4 Systems for fill, transfer and service of fuel oil

The basic principle of the fuel oil system is presented in figure 3.2. (Appendix 3). In normal conditions the machinery is operated with HFO (Heavy Fuel Oil) but can use MDO (Marine Diesel Oil) as a secondary fuel. The HFO tanks are located in fuel oil treatment room with feeder and booster units – with the exception of booster unit serving after main engines. In normal running mode, the feeder/booster units supply HFO to both main engine rooms. In SRtP scenarios, involving the fuel oil system, the supply piping between main engine rooms is cut off with manually operated isolation valves and the system is split into two independent circuits. This requires changing fuel oil from HFO to MDO. This is done by either using remote operated valves from IAS or locally next to the units. Also, the sludge and drain oil system must be split into own circuits by manually operated valves, if the fore part of the system is damaged. There is an intermediate tank for after main engine room's drain oil. All necessary power supplies are duplicated.

The interpretations state that the fuel oil system must be guaranteed when propulsion and power generation equipment is active. The regulations also apply to other flammable liquids and fluids dangerous if heated to high temperatures (within pipes or in equipments) [10]. In these scenarios the part of the system within the damaged space must be considered nonoperational.

If same type of arrangements is used for fuel oil systems in the future, there could be potential for automatic or remote controlled features. For example, turning off fuel supply to a space with a fire alarm could be arranged by IAS. Also, splitting the system into two independent circuits could be remote controlled.

3.5 Internal communications system

Spirit of Britain has two separate internal communication systems: PA (Public Address) system and UHF (Ultra High Frequency) radio telephone system. The PA system consists of two independently operating main racks with designated loudspeaker networks - extending over the entire ship. Both main racks have a duplicated power supply. Announcement units are located at the bridge and in ECR (Engine Control Room). Wireless UHF radio telephone system uses two set of antenna networks, both main racks having their own branches. The antenna networks use a leaky coaxial cable to provide a larger wireless network area. Fixed radio stations are located at the bridge and ECR, and there are three charger units around the ship for portable radio telephones.

According to interpretations, internal communication must be provided by fixed or portable means of communication. Portable system is approved if repeater (or equivalent) remains operational after a casualty and there is charging capability in more than one main fire zone. The PA system (general alarm system) must remain operational in all other main fire zones except the zone where a space or the entire fire zone is lost. [10]

The internal communication systems have been found easy to use and functional. Special interest should be placed on cable routing for UHF system as all compartments of the ship should be reachable in any SRtP scenario.

3.6 External communications system

External communication system is comprised of fixed and portable GMDSS (Global Maritime Distress Safety System) equipment. GMDSS is an international agreement for communication protocols, safety procedures, equipment and so forth to help rescuing distressed naval vessels. In the reference vessel, the redundancy for GMDSS equipment is arranged by placing redundant equipment in two different main fire zones: the fixed GMDSS unit is located at the bridge, with a charger unit for portable equipment at the Safety Center. A second portable unit charger is placed in office room at deck 8 – in different main fire zone.

The current interpretations demand portable GMDSS equipment by stating that a ship should be capable of communicating via GMDSS even when the fixed GMDSS unit is not operational [10].

3.7 Fire main system

The fire main system consists of three main vertical riser lines, connected by four main horizontal pipes. Together they form a ringline-type backbone for the system. The basic idea is presented in figure 3.3. (Appendix 4). The vertical riser lines are enclosed in fire proved “A-60” rated trunks from deck 5 to the top of deck 7. Each trunk comprises of two valve centers. Valve centers are connected to each other by the main horizontal pipes at decks 5 and 7. The valve centers are not considered part of any casualty scenario and thus are always operational. In all cases, one complete horizontal line between valve centers is intact. As so, all valve centers are connected to each other and operational in every SRtP and Orderly evacuation scenario.

The backbone network is supplied by three fire pumps, using sea water from three sea chests. The capacity of two fire pumps is enough to provide sufficient system pressure. The pumps are located so that only one pump at a time can be lost during an SRtP scenario. Water from the pumps is led to the valve centers and distributed to fire hydrants around the ship. The ship is divided into sections containing a specific number of fire hydrants. All sections can be isolated by manually operating a section isolation valve from a valve center. Needed distribution pipe segments between fire hydrants and valve centers are fire insulated.

The interpretations state that while an automatic start for remaining pumps is advisable, it is not obligatory, and that manual local start may be accepted. They also demand that all intact spaces after a casualty must be accessible with fire hoses, either from the same or adjacent main fire zone. [10]

3.8 Fixed fire-extinguishing systems

Fixed fire-extinguishing systems are divided into four sub-categories: drencher system, CO2 system, sprinkler system and fire main take-offs. Drencher system protects the trailer decks of the *Spirit of Britain* using sea water. CO2 system is intended for protection of main engine rooms, fuel oil treatment room and emergency generator room, and operates by replacing oxygen with CO2 from the space. Sprinkler system protects almost all other manned spaces of the ship, not protected by other fixed fire-extinguishing systems. Fire main take-offs are specially designed solutions for specific problems in the design of the reference vessel.

3.8.1 Drencher system

Drencher system is supplied by two drencher pumps located at forward and after main engine rooms. In case one pump is lost, there is an emergency connection to fire main system where two fire pumps are needed to replace one drencher pump. The pumps supply sea water to main distribution network, which is enclosed within a fireproofed “A-60” rated trunk.

Trailer decks are divided into drencher sections and each section has a designated manually operable section valve – also protected by the trunk. The system is a dry pipe system and water is supplied with a constant pressure only to the trunk. From the trunk, water is supplied to the nozzles if the section valve is operated.

Regulations and interpretations state that one section can only serve one deck area in one main vertical zone – except in stairways where all levels can be protected by the same section. Section valves must be protected by “A-class” fire insulation or specific water nozzles. [10]

Drencher system could be considered as a system for further development. Instead of manually operating a valve from a location with difficult access, valves could be remote controlled from an always manned position.

3.8.2 CO2 system

CO2 fire-extinguishing system is intended for main engine rooms, fuel oil treatment room and emergency generator room. Fuel oil treatment room is equipped with two separate pipelines for redundancy. The CO2 is stored in a separate CO2 room. Releasing of the CO2 can be performed locally (by manually opening the bottle valves) or from pneumatic remote controlled switches from emergency control space. All spaces are equipped with both audio and visual alarms – subjected to SRtP ruling.

Current interpretations demand that the capacity of the CO2 should be enough to protect two of the largest spaces. Additionally, there should be two rooms – not part of a same casualty scenario – both containing enough CO2 for protecting the largest space. If one of the protected spaces is lost, it should not affect the functionality of the system in other protected spaces. [10]

Development of CO2 could focus on examining the possibility of remote control from a combined emergency interface. The amount of machinery space in most ships built in Rauma is unlikely to increase. As so, the CO2 system arrangement will probably remain as described above.

3.8.3 Sprinkler system

A pressurized sprinkler system resembles fire main system's basic principle. The backbone distribution piping is formed by six valve centers, enclosed into three "A-60" rated fire proofed trunks (same valve centers as in fire main system). Valve centers are connected by a fire insulated horizontal main pipe at deck 7. The distribution network is supplied by a sprinkler pumping unit, supplied with a duplicated power supply. The unit uses fresh water from fresh water tanks. Fresh water is used to avoid corrosion in the piping network. For redundancy, there is also a connection to fire main system if the sprinkler pump unit is not operable.

From the valve centers, the water is distributed to designated sprinkler sections with individual piping. Piping is arranged from the top or bottom part of the trunk. As with drencher system, the section is formed by an area in one main fire zone at one deck. Each sprinkler section has a section- and alarm valve -pair within a valve center. Necessary pipe segments between sprinkler nozzles and valve centers have been fire insulated. The basic principle is shown in figure 3.4. (Appendix 5).

Sprinkler indication is provided to three separate main fire zones. Bridge is equipped with main indication panel, ECR with back-up station and each zone has a sub-station. The stations are connected in a two way ring topology and the indications of one complete main fire zone at a time can be considered lost. That is to say, that indication of activated sections outside the main fire zone containing the lost space, remain operational.

All of the current interpretations and regulations are met in *Spirit of Britain*: Section valves are sufficiently protected, indication is provided to operational main fire zones and hydraulic calculations are provided [10].

3.8.4 Fire main take-offs

Fire main take-offs are special solutions assigned only to problems found during the design and building phase of *Spirit of Britain*. These include water protection for paint store, heeling room and "A" class trunk for port side shaft line. These arrangements will not be examined further in this thesis as they can be considered special cases for specific problems.

3.9 Fire and smoke detection system

Fire detection system consists of two central units – at the bridge and in ECR. Both units are supplied with duplicated power supplies with an automatic changeover. There is a single fiber-optic data cable between the units for data transfer. If the main unit at the bridge is damaged, the back-up station in ECR will automatically take over the system.

Ship departments are supervised by 15 fire detection loops, 3 loops are used for indication of fire doors and –dampers. Each loop consists of an address unit in each space, with connections to the sensors, and has a set of detectors and manual call points. The loop is connected to both central units. In case a SRtP scenario, the detection loop is cut into two segments by short-circuit isolators, isolating the damaged area. Both intact segments are automatically controlled by the central unit to which the segment is attached to. If the communication cable between central units is damaged, some automatic features (related to fire doors and –dampers), handled by the main unit at the bridge, must be manually operated from the ECR back-up unit.

The fire alarm system is connected to several systems for automatic or remote controlled features, such as: fire door operations, IAS for common alarm signal, internal communication system (PA system), control of lifts and garbage chute, fire dampers and ventilation, voyage data recorder, local extinguishing systems and fire patrol system. Fire patrol check points are connected to the loops and must be noticed during certain time intervals.

The interpretations state that the system can be considered lost only in spaces directly affected by the casualty or spaces which are part of the same section. However, detectors of the same section on other decks must remain operational. [10]

3.10 Bilge and ballast systems

In *Spirit of Britain* only the bilge system is considered to be under SRtP regulations (by the Administration). The bilge system is intended for removal of flooding or fire-fighting water. The system comprises of a main pipe line, located at deck 1 and extending over the entire length of the vessel. Each compartment has smaller suction lines, with remotely operated valves, attached to the main line. Water can be removed with three different bilge pumps, located at the fore, after and middle of the ship.

In normal conditions, bilge pump number two (located at the middle part of the ship) can handle the entire ship. If a compartment, containing the main line, is lost it can be isolated with manually operated bulkhead valves. Bilge pump number one serves the isolated forward part of the vessel, and bilge pump number three serves the after part of the system. All pumps' power supplies are duplicated with manually operated changeovers, and all pumps can be operated locally.

Bilge level alarm system is also under SRtP regulations and is built as fully redundant. The redundancy is provided by duplicated sensors connected to IAS. Sensors and their cable routes for the same compartment are design never to be part of the same casualty scenario.

The interpretations allow the use of local operation for the pumps if fixed or portable communication is provided [10].

3.11 Power-operated watertight doors

Power-operated watertight door –system comprises of indication for the door status. At deck 2, between each watertight compartment, there is a watertight door. Each door has a limit switch unit with duplicated outputs and cable routes. Cable routes are designed never to be part of the same casualty scenario. The indication must be operational in all casualty scenarios, except those where the door is considered lost. The power and control unit for the doors is located at the bridge with two input ports and a changeover unit. If the primary signal is lost, the unit will automatically switch to secondary port. Status of the doors is shown on a specified mimic panel.

The regulations and interpretations state that the status of all doors must be shown in all casualty scenarios which do not exceed the casualty threshold (Orderly Evacuation situations) except when the boundary spaces are considered lost (the door itself is considered not operational) [10].

3.12 Systems intended to support Safe Areas

Designs for Safe Areas do not determine any operational patterns – only criteria for design. Certain system and equipment must be provided in all Safe Areas according to SRtP regulations. The reference vessel has three Safe Areas, all located in different main fire zones with direct access to embarkation stations. Transition between decks is provided for all main fire zones. According to interpretations, the space of Safe Areas should be designed in a way that on SRtP voyages longer than 12 hours there is a minimum space of 2 m^2 per person. On SRtP voyages shorter than 12 hours, the area should be no less than 1 m^2 per person [10.].

Each Safe Area has a sanitation system with public toilets – using sea water flushing system. The toilet flushing system can operate with either toilet flushing pump or secondary water supply from technical water system. The toilets are grouped into forward and after toilet groups shown in figure 3.5 (Appendix 6). Each main fire zone can be isolated via manually operated valves. The black water system is based on gravity and collected into two separate tanks, one for each toilet group. The interpretations state that one toilet for every 50 persons should remain operational and black & grey water could be disposed of into the sea [10]. The capacity for sanitation is calculated and proved sufficient in all SRtP scenarios.

Water to Safe Areas is provided from potable water system. As a back-up, 500 milliliters of bottled water is stored with each life jacket. The new interpretations require a minimum of 3 liters of water per person per day. Additional water for food preparation and hygiene could be demanded, depending on operating patterns [10]. Each Safe Area has a dedicated food stock for instant demand. The interpretations do not determine what kind of food is required or any quantities for stocking [10].

Medical care is provided from the ship's hospital and/or from a portable doctor's bag, located at a first aid station in a different main fire zone. All Safe Areas are located indoors, ensuring shelter from weather and preventing hypothermia/heat stress. There is also one thermal foil blanket per life jacket stored as additional measure against hypothermia. According to new interpretations, the temperature within internal Safe Areas should be between 10 to 30 degrees Celsius [10].

Lighting in main fire zones is arranged by double network with triple power supply system, with each main fire zone and deck having its own network system. Power supplies have a living changeover between them, varying according to capability. Portable rechargeable battery operated lighting is acceptable in spaces not covered by a ship's emergency lighting system [10].

In *Spirit of Britain,* ventilation of Safe Areas has been excluded from SRtP scope under mutual decision between all parties (Administration, owner and shipyard). However, ventilation volume should be at least 4.5 m^3 per hour per person if included into the scope [10].

3.13 Flooding detection system

Flooding detection system is arranged to supervise spaces on decks 1, 2 and 3. The system consists of flooding alarm panels at the bridge, IAS, duplicated sensors and a loading computer. Sensors are placed in watertight spaces below the bulkhead deck if the space has a volume which is "more than the ship's molded displacement per centimeter immersion at deepest subdivision; or a volume more than 30 m^3" [6].

All sensors are duplicated, with one sensor connected directly to the alarm panel and the other to IAS. Cable routing is designed in a way which ensures that either sensor remains intact, unless the space containing the sensor itself is damaged. Loading computer receives data from level gauging system and dry space level sensors, and is connected to the flooding system. The loading computer uses the information it receives from flooding sensors for calculations and estimates.

In all fire casualty scenarios, except spaces directly affected by the fire, flooding system must remain operational [10].

3.14 Other systems determined by the Administration

In the reference vessel, the Administration did not determine other systems to be considered under the SRtP regulations. However, with mutual decision, production and distribution of electric power and IAS were added as systems under the regulations. IAS is discussed in later paragraphs.

As with the propulsion system, production and distribution of electric power system is complex and dependent on multiple auxiliary systems. In this thesis the basic concept is introduced briefly. There are two main switchboards (located in different spaces and main fire zones) both supplied by a set of individual diesel generators (two). Both switchboards can also be supplied by shaft generators when the vessel is on sea mode.

This resembles the same concept as propulsion system with two independent main engine rooms and shaft lines. In emergency cases these switchboards can be connected together with a bus tie connection (other switchboard supplying consumers connected to the other switchboard if the generators are lost). Also, there is an emergency generator for emergency situations. The basic distribution network for SRtP purposes is shown in figure 3.5 (Appendix 7). The system is designed to sustain needed electric power for all essential systems in SRtP or Orderly Evacuation scenarios.

4 AUTOMATION DESIGN

STX Finland AS (Rauma shipyard) is responsible for the basic design of automation on board its vessels. Automation as a term is used loosely as it is supposed to cover all input and output data from measurements to remote controls, as well as fully automated functions. The more detailed automation design is done by subcontractors. At present, systems are designed individually and all aspects – including all desired I/O points – are decided by the system designer. Some systems are supplied by subcontractors with turnkey principle – including all automated functions. Most ships constructed in Rauma shipyard use a distributed automation system – generally called IAS (Integrated Automation System). IAS is connected to some separate systems and is responsible for variety of I/O functions. Automation design in the shipyard is mainly focused on the basic design of IAS. Systems with internal automation are mostly handled by subcontractors and only connections to IAS are acknowledged.

4.1 Current automation design process

IAS can be categorized as a SCADA (Supervisory Control and Data Acquisition) system. A SCADA system consists of HMIs (Human Machine Interface), Supervisory or Process Stations and Field Equipment, such as RTUs (Remote Terminal Units) and PLCs (Programmable Logic Controller) [13]. A SCADA system rarely *controls* any real-time processes, and in *Spirit of Britain* processes which need real-time control are usually controlled by independent sub-systems (such as main engine automation system).

At present, the automation design process for IAS starts with the client’s contract specification. All systems are assessed for the amount of wanted I/O points under IAS. From the system assessment, the automation designer acquires an estimate for the total amount of I/O points for the vessel. After the total amount of points is estimated, number of points for different type of connections (hard connections, serial lines etcetera) is specified, including interfaces to independently acting systems. The number of operation stations and their locations are decided, as well as HMIs, in accordance with the owner. These decisions will evaluate the need for monitors, printers, mimics and so forth. From the gathered information, a realistic calculus is carried out for basic design phase and possible supplier negotiations. After successful negotiations with the supplier, the basic design process can be carried out. [14]

The basic design process starts with raw information from the owner’s contract specification. After this, the shipyard prepares its own specification according to basic system designs (shipyard’s counteroffer for requests). At this point, the system is fairly realistic and almost all I/O points are known. This determines the number of I/O cabinets needed and lays foundations for first version power supply and cable diagrams. When systems are more defined, an I/O list is assembled. From that point onwards the automation system is perfected along with system designs. All necessary information must be known before IAS factory tests for hardware and software design, done by the IAS supplier. [14]

4.2 Design process and SRtP regulations

The automation design process is incomplete when we look at it from a SRtP point-of-view. At the moment SRtP ideology is only taken into consideration when designing system layout for IAS process- and I/O cabinets, and their power supplies. The system is distributed (process- and I/O stations) and system cabinets are located in different spaces to add redundancy (according to casualty scenarios). Cabin power supplies are duplicated and supplied from two set of UPS (Uninterrupted Power Supply) systems, and redundant cable routes are designed in a way that they are in the same space only when in the space of the system I/O cabinet. That is to say, that power supply and information is redundant but control of a sensor/actuator may not be redundantly designed and/or connected to IAS. Also, the use of wanted features can be scattered around the ship without specific HMIs.

In future SRtP development for automation, there are two main areas which should be acknowledged:

a) SRtP decision making/aid by automated system(s)
b) Automated/remote controlled actions for retaining system capabilities

At present the decision making for a SRtP situation is done by the chief engineer of the ship with no aid from a specific system or centralized information. The reference vessel has a dedicated decision support system for SRtP situations but the system does not give any information to determine whether or not the ship must be considered to be in SRtP mode – it only aids with instructions after the decision to use SRtP features has already been made. That is to say, the chief engineer must visually observe the situation, rely on information from the crew and gather information from different systems scattered across the ship to determine if the casualty scenario is severe enough for use of SRtP features. This may take some time, depending on severity of the casualty, and automated assistance may be needed - especially if we consider the possibility that recovery time could decrease and insurance issues for misuse of SRtP features could become concerns in the future.

The use of remote operations and automated functions must be considered as an option for retaining system capabilities and (for decision making), if the regulations become stricter (for recovery time and the amount of included systems). In *Spirit of Britain* all actions to recover system capabilities are done manually, except few valve actions in unreachable spaces. The amount of manual actions in SRtP situations is expected to rise in the future, whereas the recovery time will decrease. In the case of *Spirit of Britain*, the most extensive casualty scenario requires 39 manual actions [15]. The SRtP recovery time for the reference vessel is two hours during which the actions must be performed. Single operator simulations have shown that in some scenarios it takes more than an hour to complete all necessary actions. In new ships the recovery time is already reduced to one hour. This adds pressure to either use remote control and/or automated features drastically reduce the amount of manual actions with design enhancing or significantly increase the amount of operators. As so, the design process for all systems using automation must be developed further – taking into account the growing need of information for decision making, possible future need for control, and keeping in mind that these features must be redundant in every casualty scenario.

5 ANALYSIS FOR SRTP DEVELOPMENT

Future SRtP development in Rauma shipyard can be divided into four basic categories: developing SRtP regulations and interpretations, developing ships operating procedures and capabilities in SRtP situations, improving SRtP system concepts and improving testing and support services. The STX shipyard in Rauma is part of IMO's developing committee for Safe Return to Port regulations. As part of the systems analysis, the interpretations were examined for system requirements (and potential improvements).

All of the SRtP system design concepts in *Spirit of Britain* can be considered adequate for current regulations and demands. However, potential developments in the future may force designers to come up with alternative solutions for systems' structural design, wanted features and used design models. The decreasing recovery time leads to structural changes in systems or use of automated/remote controlled functions. Identifying these systems is done by using different filters and determining which of the system concepts need improvement. As one of the solutions for system development is the use of automation and remote control, IAS and other related automation systems are automatically considered as systems for further assessment.

Systems are examined and indentified from the following perspectives:

- Feedback gathered from the operators of the reference vessel
- Existing potential for use of automated functions
- Economical strain on current design because of SRtP regulations
- How the system is designed to react when equipment is considered damaged
- The amount of different manual actions for a system

Due to the possible improvement of system concepts, ships operating procedures in an emergency situation are examined. This could lead to further development of certain systems and capabilities, beyond SRtP systems, as well as more defined regulations and interpretations. Finally, testing and support services were analyzed.

5.1 SRtP systems analysis

The amount of manual actions per system was calculated. Manual actions are taken as filtering criteria because as the time needed for locating and executing them greatly affects the used recovery time. The results are presented in table 5.1. According to the analysis, there are six systems strained by large amount of different manual actions.

These are: propulsion system, fuel oil system, fire main system, sprinkler system, bilge system, and production and distribution of electric power.

Table 5.1. *Manual actions per system [15].*

System:	Actions:	System:	Actions:
01	50	08.3	33
02	3	08.4	3
03	4	09	0
04	24	10	25
05	0	11	0
06	0	12	9
07	55	13	0
08.1	4	21	20
08.2	0	22	0

From these six systems, all except propulsion- and production and distribution of electric power system possesses potential for development of automated features or concept enhancing. In the other two systems, there are several different types of operations, located apart from each other. This would mean rather expensive solutions compared to the current ones. However, propulsion system does have potential for improvement without automated features. The rest of the six systems possess qualities enabling easier options for development for automated features: manual actions comprising of same type of actions, actuators are located reasonably close to each other, the system uses same response for damage in most scenarios, and there is existing infrastructure nearby.

Economical strain caused by SRtP features was determined by interviewing SRtP designing coordinators. From SRtP systems in *Spirit of Britain*, the following systems required substantial economical investment due to SRtP demands: fuel oil system, internal communication system, fire main system, sprinkler system and flooding system. These costs are mainly caused by the redundancy features or special equipment/materials: fuel oil system needs reserve MDO tanks and a split booster unit; UHF system for internal communication requires a duplicated antenna network with leaky coaxial cabling; fire main and sprinkler system use three “A-60” rated trunks, multiple section valves and large amount of fire insulation for pipes and decks; and flooding system has multiple sensors measuring the same values. All of these qualities increase costs for the systems directly because of the SRtP regulations. [17; 18]

The Chief Engineer Officer of the reference ship, Mr. Vincent L. Todd, was interviewed to determine the operator’s point-of-view for these systems. According to Mr. Todd, the propulsion arrangement for SRtP is good. There are, however, minor problems regarding the gravity and propeller hub tanks on deck 3. He states that the features for isolation and application of the tanks will most likely never be used. He reckons that the fuel oil system has some issues he would like to sort out in the future: first being the possibility to use only one type of fuel oil. At the moment the ship must change from

HFO to MDO in SRtP situations. If in few years time car passenger ferries run only on one type of fuel oil, the SRtP concept should be upgraded accordingly. The second problem is the layout of HFO pipes between main engine rooms: at the moment they are placed on both of the far sides of the ship which makes them vulnerable in collision situations (possible flooding scenario). Instead, he would place them close to the center-line of the ship. The personnel are very pleased with the layout for fire main system but think that some of the actions and the amount of pipes could have been reduces. The use of trunks however, was praised as an excellent idea. The same pros and cons were said about the sprinkler system. There were no issues regarding the UHF system, flooding system or the bilge system. However, Mr. Todd would have made additional suction lines for all spaces containing bilge pumps for additional redundancy. [11]

As a result of the analysis, following systems were chosen for detailed revision: propulsion system, fuel oil system, fire main system, sprinkler system, bilge system and flooding system. Flooding system was chosen as a concrete example for economical calculations by the shipyard.

5.2 Analysis for regulations and interpretations

As part of the system analysis, current regulations and interpretations were examined. The main focus was to determine whether the rules allow possible future development of systems, and if the rules were realistic enough to allow economical and effective solutions in SRtP designs. Few interpretations were found insufficient or incomplete (from designer's point-of-view) and chosen for further development.

The term 'space of fire origin' is not clearly determined. That is to say, all spaces are considered spaces of fire origin – except spaces listed in regulation II-2/21.3.2 interpretation 8 [10]. This leads to additional amount of different SRtP scenarios from spaces not necessarily possessing any credible risk of fire. Instead, the ship's spaces could be analyzed for realistic possibility as a cause of fire origin in normal conditions: possible sources for ignition (electrical appliances, self-flammable liquids etc.), fire potential (combustible materials), and volume of the space. This could be compared to fire-extinguishing potential of the space.

The other area is partially related to the previous. Modern remote controlled and automated functions are usually handled with electrical control signals. Some actuators are located in secured places, not considered as spaces of fire origin, which do not require fire-extinguishing systems (such as the "A-60" rated trunks). If these actuators were automated with electrical control signals, this space would no longer be considered secure and would need fire protection from an extinguishing system. A certain voltage/ampere reading or a certain type of cable solution could be arranged to allow the use of electric control signals and not causing a risk for fire. This would encourage to the use automation as a solution for certain redundant features, and enable its use in wider perspective.

5.3 Analysis for operating procedures

There are few issues left open regarding operating procedures. One was the use of Safe Areas. The regulations and interpretations are set for designing Safe Areas but do not state any information for their using procedures. If Safe Areas must be used every time when SRtP features of the ship are used, it increases the threshold of using the designed options. Second issue involves decision making and the features themselves. The SRtP design process has been carried out by analyzing the ship's capabilities space by space, and ensuring that systems are functional if that space has been completely lost by fire or flooding. This leads to an assumption of scenario based instructions regarding each space of fire origin. However, in real life the space is rarely lost completely and the operators choose which features they will use, after careful consideration.

According to Vincent L. Todd, Safe Areas are only used in cases where evacuation of the ship is necessary or there is direct fire/flooding contact or menace for the passengers. This is influenced by the fact that *Spirit of Britain* operates on short sea voyages. On longer voyages, the use of Safe Areas could become a major designing and operating issue. Also, he states that after all fire situations, use of any SRtP feature is thoroughly considered. This is done by checking system capabilities and using redundancy only if something is not operable. Some of the features are very rarely used, even if there are suppliers' recommendations to do so, whereas some of them could be used with relative ease. [11]

For decision making, in *Spirit of Britain*, the chief engineer uses the information from fire detection system; flooding system with visuals, estimates and calculations from the ship's loading computer (if flooding cases would be consider as part of the SRtP scope in *Spirit of Britain*); CCTV cameras and, most importantly, the personnel [11]. The advantage of the reference vessel is that it operates on short sea voyages and it has a large amount of personnel on board at all times. Gathering the needed information from the systems is easy on *Spirit of Britain* but he noted that may not be the case on other vessels – especially on ships with unmanned engine rooms.

The use of Safe Areas and SRtP features varies with every ship. As so, the SRtP design process should aim for methods which are adapted to worst case scenarios but enable the operator to choose from the list of possible operations. The aid for decision making should be designed for unmanned ECRs which would guarantee sufficient information with or without adequate amount of crew on board, and to give sufficient information about the use of Safe Areas.

5.4 Analysis for testing and support

Testing for SRtP systems is done in various stages, depending on the system. Some of the systems are tested in factory and/or supplier tests. Most of the testing (especially regarding SRtP systems) is done in either quay trials or in sea trial(s). With *Spirit of Britain* most systems were proven redundant before trials, with theoretical analysis and evidence. Special focus was placed on features with double significance to avoid unnecessary testing (testing the same feature more than once).

Most of the SRtP related systems were tested during quay trials. Separate SRtP tests were replaced with more extensive quay tests. All of the SRtP features were numbered with individual coding to ensure that all the features are tested and approved. Some tests, such as the changing from HFO to MDO, could not be performed during quay trials. These tests were carried out during sea trial. The sea trial is done to test and tune the ship before it is delivered to the owner. Sea trial test is as close to a normal operating environment as possible, and therefore gives valuable information on how the ship acts during normal running mode.

One issue which was raised during the feedback was SRtP training. Mr. Todd thought that the shipyard could, in accordance with the ship's normal operating practices, provide better training for SRtP systems [11]. This could contain the use of decision support system, possibly going through different SRtP scenarios and explaining each system and their redundant features. The training would give background information on the theory behind certain solutions, and would compare it to real life situations and ship's operating practices. Training would also prepare the personnel for the provided SRtP material for self studying.

Separate support or training on SRtP related issues were not coordinated or organized for *Spirit of Britain*. Technical support of the systems is arranged under the warranty agreement of the entire vessel. The information exchange between developments and matters was informal and happened during normal information exchange. The owners had one person carrying an interest towards SRtP related issues, where as the shipyard had two project coordinators. Shipyard had tentative ideas to train their personnel regarding SRtP related topics but nothing concrete happened after first meetings. Training of the ship's personnel is purely based on the materials (analysis, instructions and diagrams) received from the shipyard and handled by the ship owners – without support from the shipyard. Developing a training program for the whole field of SRtP could improve the quality of the product.

6 DEVELOPMENT OF NEW SRTP DESIGN CONCEPTS

The development process of systems follows the concept shown in figure 1.3. User and system requirements were examined in previous paragraphs and now form the basis for new architectural designs. Feedback is gathered from system designers and project coordinators along the way. Based on the analysis of the reference systems, selected systems are exposed to the development process. The aim of this process is to find modular designs which could be used in all car passenger ferry types, and which would fulfill one or more of the following criteria: reduce manual actions and/or the amount of SRtP scenarios from previous model; is cost-effective compared to the reference model; enables a possibility for remote controlled features; and is feasible according to the current SRtP interpretations. The process also acknowledges the ship as a single entity and ensures that the functionality of the whole ship in emergency situations is enhanced – through development of regulations (or interpretations), operating procedures, systems and testing. Flooding system concept is selected as a concrete example of economical calculations.

6.1 Regulations and interpretations

During the analyzing phase, two areas of the current interpretations of the regulations were found confusing or inadequate to support cost-effective and feasible SRtP concepts. These two were the interpretations regarding which ship locations are consider space of fire origin, and – related to the previous - use of electrical control systems without causing a secured space to turn into a space of fire origin.

At present, by default all spaces on a passenger ship are considered a possible space of fire origin – regardless of its realistic potential as a source of ignition or its possible fire load. Only spaces stated in regulation II-2/21.3.2, interpretation 8 are considered spaces where the risk of fire originating is negligible [10]. These spaces include:

- void spaces
- trunks closed at all boundaries
- cofferdams
- tanks and chain lockers
- some ventilation trunks
- cross flooding ducts connecting void spaces
- vertical escape trunks

- store rooms for gaseous fixed fire-extinguishing systems
- bus bars enclosed in “A” class divisions
- shaft tunnels only used for this purpose

The present interpretation aims for a clear rule dedicating these spaces. All spaces can be reasoned to be spaces of fire origin with countless ‘ifs’ and ‘buts’. However, it can be questioned whether this type of approach is reasonable. While this type of thinking definitely increases the level of safety by declaring that all spaces contain potential risks, it also brings up the design and production costs of systems with some unrealistic menaces. It would be more beneficial to realistically analyze ship’s spaces individually to examine the possibility of a fire in normal operating conditions (caused by systems themselves). This would change the forming of SRtP scenarios from a theoretical basis to more realistic assessment of situations, and would, in most cases, avoid unwanted and expensive solutions in locations where they are not needed.

As an example, a machinery arrangement diagram of the heeling room in *Spirit of Britain* is shown in figure 6.1.

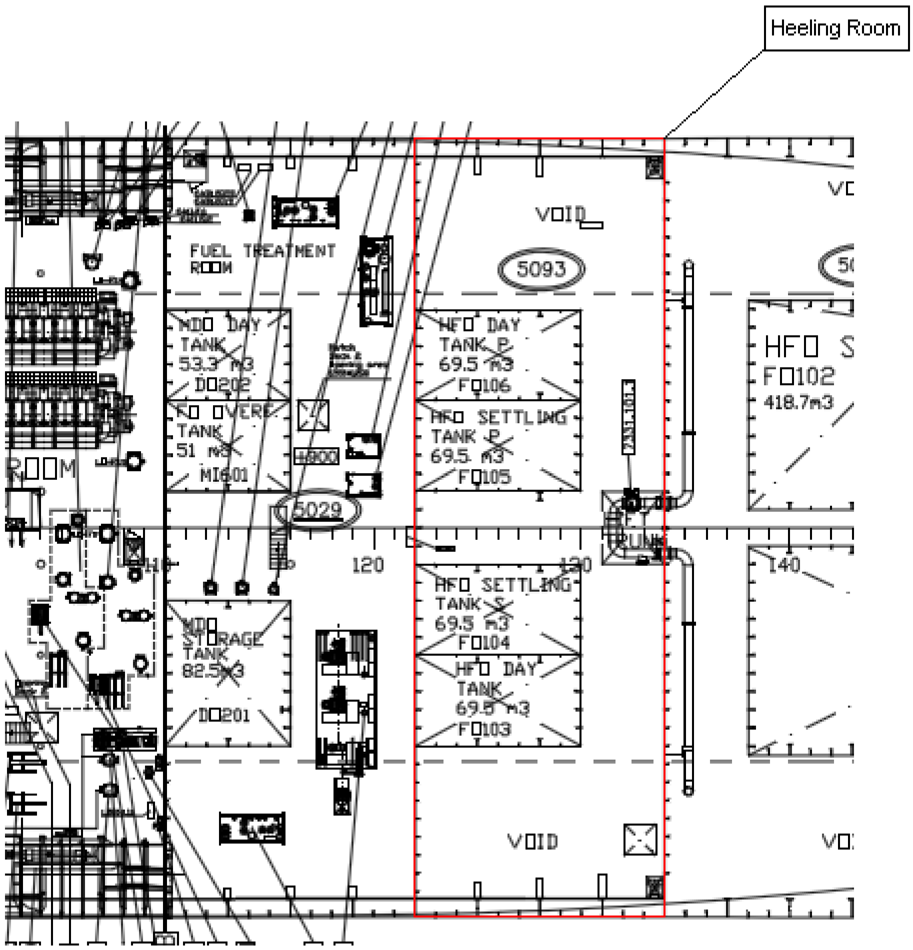

Figure 6.1. *Heeling room machinery arrangement [19].*

As can be seen from the machinery arrangement, the heeling room is basically a void (with a volume of approximately 1035 m^3) containing few tanks (also in tank top) with negligible fire risk, a heeling pump for the heeling system and two ventilation fan motors. There are no fuel oil pipes passing through or serving the space nor is the space used for storage. There are cables going through the space but only few serving the space (having connections inside the space). The bulkheads and hull are made of steel-based structures and alloys. Yet according to the interpretations, this space is considered a space of fire origin. As a result, all pipes, cables and equipment, or their segments, located in the space must be analyzed and designed redundant, and the space must be equipped with a fixed fire-extinguishing system. During the analyzing process, the whole space and all its contains are considered lost - when in practice, the probability of a self-ignited fire in heeling room, where the space is lost completely, is extremely small.

Instead of automatically declaring all ship's spaces (except the ones categorized by Interpretation 8) 'spaces of fire origin', all departments should be assessed during the early stages of the design process. This would ease the analysis needed during latter part of the process. All the spaces could be divided into three categories: potential, negligible and insecure. The first two categories would be used to eliminate the definite cases from the process (such as the spaces from Interpretation 8 or spaces always considered risky, such as machinery spaces). Spaces belonging to the third category, insecure, would be assessed more thoroughly.

The assessment should examine at least the following things: source and risk of ignition, fire load and materials in the space, volume and distances (heat transfer), and the relations between the three. Each theoretical elimination of a space, from the list of possible spaces of fire origin and due to this assessment process, should be proved either by predetermined values, probabilities or reference materials. If the assessment would be conducted for the heeling room in *Spirit of Britain*, it would show that even if the space possesses a credible source for ignition, the fire load, distances and internal relations between them do not indicate that the whole space would be lost. The most likely scenario is a short-circuit in the electrical installations or a small fire at the pump or the fan motors. The fan motors and the pump are located relatively far from each other, the space does not store any materials with high fire loads and the structures are steel based compounds. The probability of a fire, under normal running mode conditions, would be very small. As a consequence, the SRtP systems should not be analyzed in case of a fire originating from the heeling room.

One issue which is related to the problem regarding the 'space of fire origin' – categorizing is the use electric control systems. According to the old interpretations, each space containing electrical appliances is automatically considered a space of fire origin. This effectively rules out the use of remote controlled features, carried out by electric control signals - especially when actuators are situated at spaces with negligible fire risk. However, the new interpretations allow the use of certain solutions, executed according to specific standards, to survive casualty scenarios (such as the use of fire resistant cables) and the reference vessel has an example of a space with negligible risk of fire containing electricity and contradicting the interpretations.

As an example, in *Spirit of Britain* all valve centers contain sprinkler section isolation and indication valves. The sprinkler section indication system is realized electrically. The same interpretation states that only electric cables (without connections) can pass through the trunk but later describes that section valves (always comprised of isolation- and an indication valve) can be placed safely inside the trunk.

One aim for future development should be changing the regulations considering electrical appliances and signals. The use of fire resistant cables is a step in the right direction but the use of electric control signals should be made more feasible. This could be done by agreeing specific ampere or voltage levels (considered not to cause a significant fire risk); use of certain designs and concepts; and following methods and standards for electrical equipment in hazardous areas (ATEX directives).

6.2 Operating procedures – Safety Center

One of the problems with SRtP regulations is that the regulations are set for designing the ship. There are no guidelines for the actual operating procedures during real life SRtP situations. At the moment, handling different emergency situations is left entirely to the ship's personnel. The personnel are trained for certain situations but mostly have to rely on information from safety cards or emergency materials. Additionally, there are no specific means for observing or decision making if a ship is/or will encounter an emergency situation - such as SRtP scenarios. Even though different designs and structures are carried out to prevent such situations, there should be a level of readiness if an emergency situation happens. Also, in emergency situations the use of Safe Areas and specialized system features are not clearly stated anywhere, and are decided on a case by case principle by the chief engineer (in *Spirit of Britain*) [11].

At present, the reference vessel has a dedicated decision support system for SRtP situations (instructions) and a separate Safety Centre for management in emergency situations. The SRtP decision support system is a specifically constructed computer program (on two fixed locations) which needs to be started if a casualty scenario occurs. The program only gives information and instructions after the decision for a SRtP mode is already made by the chief engineer.

All passenger ships have a Safety Centre on board due to SOLAS regulations. When a ship encounters a SRtP scenario, it is considered an emergency situation according to SOLAS [6]. The existing Safety Center could be upgraded to assist and control all possible emergency situations the ship could encounter (fire and flooding situations, pollution, actions against the ship's or its personnel's safety, assistance to other ships etcetera). The Safety Center concept would offer information both *before* and *after* a decision of an emergency situation is made – aiding the operators in decision making regarding the severity of the situation; anticipating and estimating future turn of events; giving instructions; providing communications; remote controlled operations; use of Safe

Areas etcetera. The remote controlled features could be chosen from a list of suggestions, according to the operator's wishes. Safety Center could provide data from operable propulsion systems and maneuvering capabilities, calculations for maximum distance or speed with one shaft line and remaining fuel supplies, a list of lost or malfunctioning equipment or systems, anything required by the chief engineer and the captain.

At present, most used systems on a ship are independent and are not connected and communicating with each other. This means that information and separate operating stations are scattered across the ship. The Safety Center at the bridge is a step to the right direction. It already centralizes some needed information, possesses means for communication and in some cases control. This concept should be further developed, first by making it redundant. A redundant Safety Centre concept would guarantee a centralized place for control and coordination in any given emergency situation, including SRtP situations. As an example, in *Spirit of Britain*, two Safety Centers could be arranged – one at the bridge and one in the ECR, located next to main engine rooms. Both the bridge and ECR are considered highly important locations for operating the ship. Therefore, these places already posses most of the needed infrastructure for a Safety Centre. Additionally, they are usually located afar from each other, in different main fire zones, and thus cannot be part of a same casualty scenario in the sense of SRtP ideology. This ship layout for bridge and ECR is common in vessel types built in Rauma shipyard and would guarantee redundancy for the decision making process.

However, building two complete Safety Centers would not be cost-effective. Instead, the features of the secondary Safety Center could be reduced as it would be used only in situations where the primary Safety Center is lost. Ideally, the Safety Centers would have only one HMI (per Center) for all features: alarms and visuals from few screens, fixed communication options and one screen for instruction, estimates, information and control. This would mean a move from older systems (with separate alarm panels and hard connections) to a more modern one (software based systems, programmable to any kind of need). The existing list of systems providing data, communication and control (shown in paragraph 2.4) should be complemented according to needs and owner's wishes. The concept could be modified to apply to the ship owner's normal emergency protocols.

6.2.1 System integration and data network

Before the new Safety Centre concept could be implemented, there lies a problem with system integration. Car passenger ferries depend upon numerous operations performed by different systems. Some operations are executed by IAS, some by individual systems. Some of the systems are interconnected and some work independently (only a common alarm to IAS). As systems may not communicate with each other in normal conditions, there could be complications with the distribution of data across systems. Not only does the Safety Centre concept require information from multiple systems but it should also be capable of controlling some desired system features.

The SOSE approach should be implemented when designing these systems. Instead of concentrating solely on individual systems, the designer(s) should focus on systems being able to interact and share information, providing the ship with better capabilities and options. This approach would enable a sort of system of systems (with operators as part of the SOS) with greater interoperability between them. This would not only mean the possibility of exchanging feedback information but ensuring that a system, if required, could be remote controlled from a centralized HMI. Even if separate systems are integrated, the SRtP rules for redundancy in casualty cases should be kept in mind. This means that all required feedback and control signals should be redundantly achieved.

According to Huovinen, there are four different levels of hierarchy in automation systems: Enterprise Level (ERP), Management Level (MAL), Process Control Systems (PCS) and Field Level. Huovinen continues that MAL is the bridge between ERP and lower control and field levels, and therefore, key to system integration. [20.] In marine automation today, the closest reference point to MAL would be IAS process stations (and other possible equivalents in other systems). Hence, during automation design process, it should be verified that all necessary systems are physically interoperable at this hierarchy level. This requires good communications between the IAS supplier, system supplier and the shipyard (system designer). Also, the shipyard should provide coordination and clear system concepts for Safety Centre and sub-systems during the basic design phase. The suppliers should be given a clear idea what is expected from the sub-system and if it needs to be part of the data LAN (Local Area Network). Also, the supplier for IAS should be chosen carefully. The system should support multiple communication protocols and should be flexible for alterations to the original designs.

This thesis will examine system integration more from a network point-of-view; that is to say, that all necessary systems should be designed in a way that they can be installed as a part of ship's data LAN. The idea is to form a data LAN from IAS and subsystems – IAS acting as the basis for information infrastructure. For example, if we would like to remote operate sprinkler section valves from a Safety Centre and receive valve indication data, we must ensure that a turn-key supplied sprinkler system is designed in a way that it is able to communicate as a part of the ships data LAN (can be connected to IAS in a way that each section valve can be operated via IAS screen). The connection methods and techniques are left open for system designers and suppliers to choose from but some interest should be placed on the network topology, because of the demands set by SRtP rules.

The integration problems with the first two of the OSI (Open System Interconnection) layers, Physical and Data Link, can be resolved by coordination between designers and suppliers, and using ISO/ IEC 8802 standards [20]. As the successful connection of systems on Physical and Data Link layers have been confirmed, challenges with other layers must be examined. This thesis will not thoroughly assess different solutions for this problem. However, as the SOS of the ship is heterogeneous distributed system from multiple suppliers - using different platforms, protocols etcetera - and due to the trend of ships using more complex, large-scale, distributed (real-time and embedded) systems -

this thesis suggest possible third party middleware solutions (such as DDS (Data Distribution Service) or equivalent solutions) as an option [22]. Yet, other possibilities should not be excluded, and should be left open for system designers to consider on a case by case principle. However, designers should guarantee that systems requiring remote or automated functions are integrated as a part of ship's data LAN and that the information can be transferred to fulfill all expected system requirements.

6.2.2 Data network topology

Instead of software based problems, this thesis focuses more on hardware and routing related challenges. SRtP rules state that the ship's automation system must remain operational in any fire or flooding casualty scenario. To secure a fully SRtP redundant system, there must be emphasis on the importance of the data LAN topology and how it is designed, as the SRtP scenarios are formed with a space-by-space related approach.

This thesis examines the possibility of using IAS as the basis for a complete data network. It is an existing system, distributed around the ship, and already equipped with easy connection interfaces to other systems (with normal suppliers). In the reference vessel however, IAS process stations are quite centralized and I/O cabinets do not posses networking capabilities (each I/O cabinet is automatically connected to both process stations). This could cause problems, or additional installation costs, if sub-systems are connected as part of the network. One solution is to further distribute the system, using more sophisticated RTUs with network capabilities and sophisticated connections (such as Ethernet TCP/IP). A more distributed and sophisticated IAS would provide more layout possibilities, system security (from SRtP point-of-view) and possibly lower cabling costs. Yet, even if savings with reduced cable costs could be acquired, the more developed IAS would most likely increase acquisition costs. Economical aspect must be kept in mind when designing the system. However, economical aspects should not be the only designing factor, especially if system integration creates new possibilities and possible savings from other areas. There is a possibility however, that a larger network could cause problems in the future. These problems may be related with possible real-time processes working under IAS, and with network message quality, collisions and response times, depending on the network topology and used solutions.

In this case, the scope for the assessment of the system network is defined not to examine connections to sub-systems and is instead defined to only examine IAS with its connections. According to the delivery specification, the reference ship's IAS consists of two process stations, a Safety Console and 7 I/O cabinets. Two main operating stations are provided – one at the bridge and one in ECR. One reserve operating station is located at the after switchboard room. Safety Console and process stations form a logical dual ring network and all I/O cabinets have duplicated connections to both process stations (see Appendix 1). IAS is connected to following separate systems with serial line connections: Integrated Navigation System, Voyage Data Recorder, Remote Gauging System, Loading Computer, Remote Controlled Valves, Main Engines (4) and Auxiliary Engines (4) and to Propulsion Power board System. [2.]

Developing a functional concept for IAS network topology is challenging. According to Kenyon, designing a low cost, yet efficient, network topology relies on very complicated algorithms and heuristic techniques. Depending on the amount of locations (N), there is $N \times (N-1)/2$ possible links and $2^{N\times(N-1)/2}$ possible topologies for a network. [23.] For example, with 7 locations there are 2 097 152 possible topology options. This means that there is no easy way to secure the best possible option. All design processes depend on the amount of locations and requirements, called constrains. Kenyon continues that a design process starts with supporting data, gathered during capacity planning phase, and a designer should try to satisfy certain chosen constrains, such as reliability, delay-throughput and costs. [23.]

With a ship's data network, one constrain should be added - redundancy. This, however, reduces the amount of possible topologies only slightly. If less sophisticated I/O stations are used, it reduces the amount of topologies but increases the amount of cabling. Sophisticated I/O cabinets, with network options, would enable a possibility for a mixture of different network topologies, such as a logical two way ring (figure 6.2) used between the process stations, but would increase the acquisition costs.

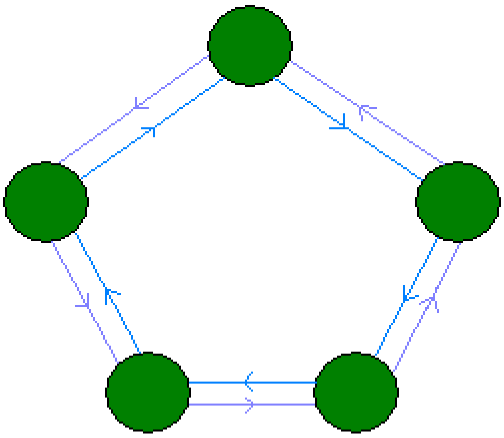

Figure 6.2. *Two way ring topology.*

The advantage with the logical two way ring topology is that it automatically secures a redundant connection. Meaning, that in any cable failure scenario there already exist an alternative cable route. This means that the SRtP rules are already partially complied. In a cabinet failure scenario, a two way ring transforms into a C-topology and information is restored as long as the sensor/actuator is connected to at least two cabinets, it is located in the same space with the cabinet or one connection is acceptably secured (fire resistant cable). When I/O cabinets are located in separate spaces and the ring cabling is carried out as straightforward as possible (cables between different I/O cabinets not entering the same space), the system should survive all SRtP scenarios. Disadvantages could be problems with message quality and response time, geographical distances and possible cabinet layout problems (depending where I/O is needed). Also, it may not be beneficial to use a single ring to connect all cabinets but instead consider (depending on the layout and distances) the use of hybrid topologies. These possibilities could be executed with several field bus protocols, using switches to form a logical ring.

6.3 Propulsion system

The propulsion system satisfyingly fulfills both user and system requirements set by the operators and regulations. However, the design could be further developed from both economical and SRtP concept perspectives. The SRtP concept for propulsion system does not seem to have potential for any additional remote operated or automated features which it does not already posses. Failures are dealt with mechanical operations – using only one complete shaft line (shutting down the other) and/or manual valve operations. Automated/remote controlled valve actions are, in most cases, not economically reasonable. Valves are scattered widely around the ship and in places easy to access. However, the amount of manual actions could be reduced with changes in the design concept.

Two groups of valves should be examined more closely. First valve group consists of isolation and application valves for stern tube emergency tank and propeller hub gravity tank. These items are lost in scenarios where the RoRo deck of the ship is damaged. The operations for isolation/application cause a lot of actions on very theoretical basis and severely influence the capabilities of the ship if applied. According to Mr. Todd, these features will hardly be used [11].

The use of gravity tanks depends on the supplier of the propellers. Gravity tanks are used to secure static pressure in the shaft line hub. As an alternative, there are suppliers who, instead of gravity tanks, offer pressure maintaining pumps. For the shipyard, gravity tanks have been used as a standard solution because it is easier to launch a ship into water with an incomplete shaft line (as, at that time there may not be working power network on the ship to supply the pressure maintaining pump). A pump model could be both a more economical solution and it could also reduce needed actions in SRtP situations. With careful layout design the loss of the pump unit could be coupled with the loss of the complete shaft line. Hence, it does not add SRtP features, only reduces them. Instead of multiple valve actions, only a duplicated power supply with automatic changeover for the pump would be needed.

Second group of valves contain the isolation valves for instrument air. The use of instrument air for main engine rooms' ventilation should be considered as an area for further development. In *Spirit of Britain* the fire dampers of both main engine rooms are pneumatically controlled, whereas the ventilation fans are electrically controlled. In SRtP sense, instrument air is only used for main engine room ventilation control. The control air is taken from instrument air system, which is connected to working- and starting air systems, provided from both main engine rooms and led to the funnel top via various decks and SRtP spaces. Additionally, the piping network for all of the compressed air systems spreads along the ship on multiple decks and spaces. A casualty anywhere on the piping network is considered to reduce pressure on the whole network.

Hence, there are a lot of isolation valve installations and analyzing work to be done for compressed air systems. This amount of work could be reduced greatly (or eliminated completely) with more sophisticated design concept.

There are at least two options how compressed air systems could be excluded from the SRtP scope. First is to change from pneumatic control to electrically controlled system. As this option would be easier from SRtP point-of-view, it would be more expensive and less reliable in emergency situations according to the project coordinator [18]. The second option is to change the design concept for main engine room fire dampers and ventilation fans. The current reference system is shown in figure 6.3. (Appendix 8). In future vessels, new interpretations allow that the supply cables for ventilation fans could be installed from VMC (Ventilation Motor Control) centers up to the fans via main engine room and the funnel, provided that the cable is fire resistant. This would mean more expensive materials but reduced costs in working hours, as the route is shorter and easier for installation. This would decrease estimated total costs. Also, the pneumatic control boxes for the fire dampers could be installed on top of the funnels, on the weather deck, which is not part of any SRtP casualty scenario. Both boxes would be fed by a common instrument air vessel or an accumulator – also located on the weather deck. The vessel/accumulator would be connected to the instrument air system with two connections from both main engine rooms via engine room funnels, equipped with check valves. With this concept, the operation of both engine room dampers in every SRtP scenario is secured without any manual actions. As with the fan supply cables, the expenses for materials would increase but the total costs would reduce with saved working hours and shorter routes.

However, there are certain criteria which must be met if the control boxes are situated on the weather deck. First, the area containing the boxes must be restricted from all passengers to avoid any misuse of the equipment. Second, the boxes must be suitably protected (sufficient IP classification). And thirdly, the used instrument air must be dried according to prevailing weather conditions on the ship's operating route to avoid unwanted freezing. The basic concept is shown in figure 6.4.

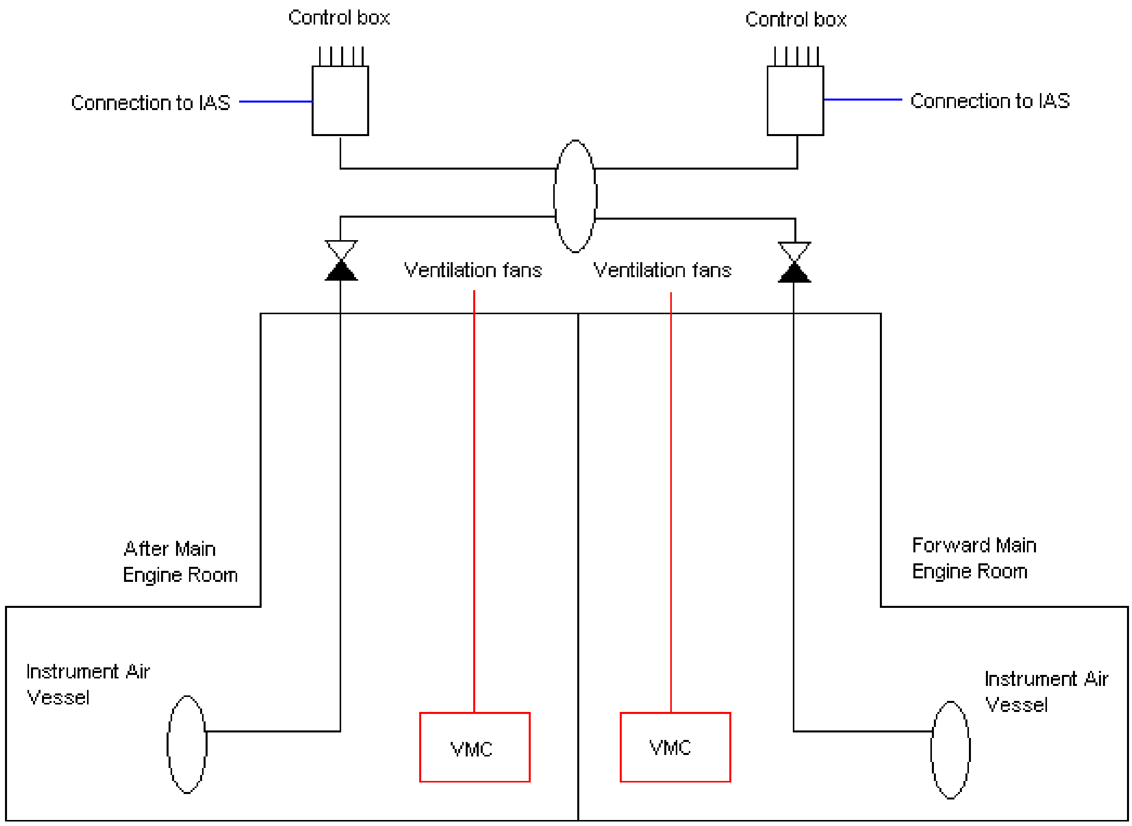

Figure 6.4. *Main Engine Rooms' ventilation concept.*

From a more general point-of-view, the aim for modular propulsion system development should be that full propulsion and maneuvering capabilities (with two shaft lines) of the ship should remain operational in all but the most extensive fire/flooding scenarios. The propulsion concept should be based on two shaft lines with four main engines in two main engine rooms (when reasonable/possible). The use of two shaft lines with four main engines allows redundancy both in SRtP scenarios and when maintenance work for propulsion system is needed. Basic design criteria should aim to reduce the amount of manual actions by design – meaning that the number of scenarios with a need of using only one shaft line would be reduced to a minimum, and manual actions is not needed except in the worst scenarios. This can be acquired with fire insulations on water cooling pipes, "A-60" rated trunks covering auxiliary systems as well as the shaft line, duplicated power supplies for auxiliary equipment and so forth.

The same concept as with fuel oil system could be applied: splitting the propulsion system into two independent circuits. When possible, a complete shaft line with all auxiliary equipments would act as an independent system. For example, in *Spirit of Britain* the main engine rooms would function as an imaginary border for splitting cooling water and fuel oil systems. Systems for port side propulsion line would use systems situated at spaces from forward main engine room to fore of the ship, and avoiding unnecessary cross-connections to starboard side system. In casualty cases, it would always guarantee one fully working shaft line, with the minimum amount of actions, and possibly the other shaft line with reduced capabilities.

6.4 Fuel oil system

The fuel oil system can be considered adequate when system requirements are considered. From operators' point-of-view, there are few issues which need development even if basic requirements are fulfilled.

First issue is the used fuel type. The main engines in *Spirit of Britain* (MAN B&W 7L 48 60 [1]) operate with two types of fuel – HFO and MDO. HFO acts as primary fuel, whereas, MDO is used in start-up-, shutdown- and SRtP situations. The operators stated that the dual quality of the motor can be considered as both positive and negative characteristic - it gives more redundancy and options in malfunction situations, but the changing over from HFO to MDO requires additional work. According to the operators and machinery project coordinator the work needed for changeover takes up to approximately 15 minutes (in SRtP scenarios). After the fuel changeover, the system requires little time to adjust and to provide the needed power for propulsion [11; 18.].

The second issue regards to the layout of fuel tanks, equipment and piping. The MDO system comprises of two independent fuel supply circuits for both shaft lines, the border between main engine rooms acting as a boundary line. The fore and after part of the ship are equipped with individual MDO tanks, pumping- and booster units with relevant piping. HFO system acts as a single system which supplies both main engine rooms. All HFO tanks are located at the fore part of the ship (day and settling tanks in fuel oil treatment room and reserve tanks at fore void spaces). The feeder & booster unit for forward main engine room is located at the fuel oil treatment room. For after main engine room, the unit is split into two where feeding unit is located in the fuel oil treatment room and the booster unit is in the after main engine room. This layout concept denies the possibility of using HFO in SRtP situations (scenarios where fuel oil system is considered damaged). One major issue is the HFO inlet and outlet pipe routes between the main engine rooms. These pipes must be isolated via manually operated valves when switching to MDO use – causing additional manual actions in SRtP situation. Furthermore, these pipes are located on both far sides of the ship (starboard- and port-side). This layout arrangement creates an unnecessary risk in collision situations (flooding situations) where pipes are more exposed to damage than the rest of the system.

When developing future fuel oil system concepts, changing environmental regulations must be noted. One important, and current, alteration in regulations covers the allowed amount of sulphur oxides and particular matters in exhaust gases. At present the allowed concentrations should not exceed 4.5% m/m. After 1 January 2012, the concentration should not exceed 3.5% m/m and after 1 January 2020 no more than 0.5% m/m is allowed. For North European Emission Control Area, (shown in figure 6.5. and considered an important marketing area for Rauma shipyard) the allowed concentrations are currently (after 1 July 2010) 1.0% m/m and after 1 January 2015 0.1% m/m. [24]

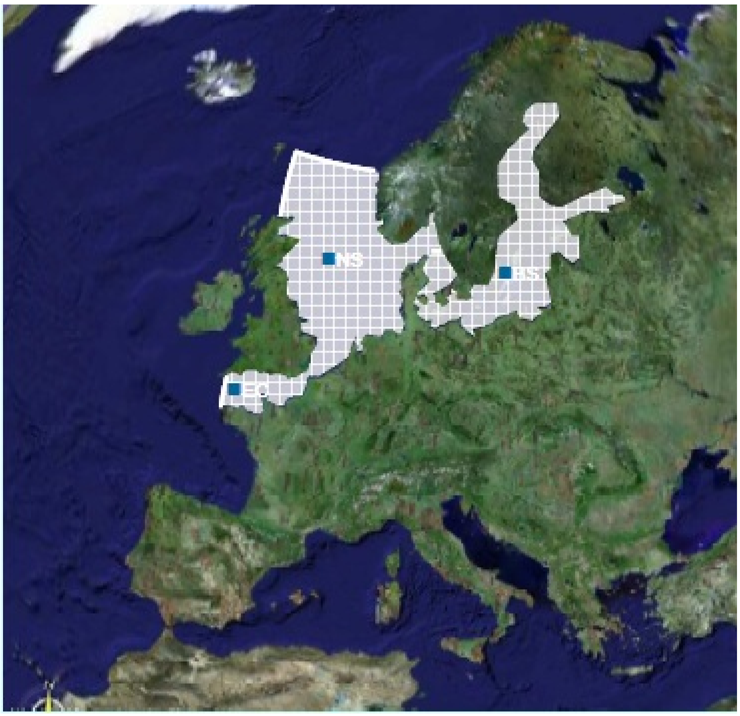

Figure 6.5. *North European Emission Control Area [25].*

The generally used fuel types for RoPax vessels are: HFO, IFO (Intermediate Fuel Oil), MDO, MGO (Marine Gas oil) and LNG (Liquefied Natural Gas). Ships are usually designed to run on two different types of fuel, especially if they are primarily run with a residual oil type. If the new regulations come into force, the use of HFO and IFO as primary fuel types comes under scrutiny. HFO and IFO are widely used as costs are severely lower compared to the other options. However, the use of residual oils strains the environment above allowed concentrations if the exhaust gases are not processed. The exhaust gases can be refined with scrubber systems but the investment costs of would make these oil types less competitive economically. MGO, MDO and LNG systems are more environmentally friendly, and through recent developments are becoming less expensive. The main issue for system development process is whether the regulations for air pollution are enforced. At present, the regulations are facing firm resistance from ship-owners. The owners believe that the restrictions will increase marine transportation cargo fees to a point where land transportation becomes a more economical prospect, which would instead strain the environment far more than moderate regulation reforms for marine transportation.

If the new air pollution regulation is enforced, the use of one fuel oil type would be beneficial from a SRtP point-of-view. This would mean that the use of residual fuel types would decrease rapidly due to high operating costs. As a consequence, the use of only one fuel type would streamline the design process: the layout of fuel tanks and equipment, pipe routes and the design for independent fuel circuits would be easier to design. Also, it would reduce the amount of work in SRtP situations: only the system itself would need actions in SRtP situations and would not necessarily require any actions isolating it from other systems. However, if the regulation is not enforced, the use of primary and secondary fuel types is likely to continue. This causes additional demands for system designers. The designer must decide whether the vessel should be able to use both fuel types in all SRtP scenarios or whether one fuel type would be available at all time. This could cause problems with the ship's structural design and balance calculations due to fuel tank arrangements. Primary SRtP concept should be based on the principle that the vessel uses only one fuel type, whenever it is possible. If two fuel types are used, for reasons beyond SRtP scope, the fuel oil concept should be designed to operate with only one fuel type and its supplying system in SRtP scenarios. The use of either fuel type in every casualty scenario should be used only if the design is feasible and economically reasonable.

The design should be based on two working shaft lines and separate main engine rooms. Both main engine rooms should be served by independent fuel treatment plants and supplying networks. These networks should be cross-connected only when it is absolutely necessary. Normal running mode fuel supply should be secured in other possible manners, avoiding unnecessary connections. However, the idea of independent fuel circuits should not exceed the security of fuel supply in normal conditions.

6.5 Fire main system

Fire main system currently fulfills both user and system requirements set by the operators and regulations, however, with a notion from the operators that the amount of manual actions could be reduced. The system however possesses potential for further development – both as a concept and/or with remote controlled features. In *Spirit of Britain*, SRtP regulations have drastically increased the investment cost for fire main system compared to the previous system models. With a more simplified design concept, the user and system requirements could be met with lower costs and recovery time.

With the new design concept the amount of sections can be drastically reduced without decreasing the operational capacity of the system. This would greatly reduce the needed amount of pipes and isolation valves, and most importantly cost of installation work. Due to new interpretations, fire insulation for distribution pipes is rarely needed – provided that the pipes meet the necessary requirements set by regulations. Also, the horizontal and vertical backbone pipes do not require any insulation or isolation valves. However, the use of insulation should be decided on a case by case principal with each vessel. This would mean that "A-60" rated trunks would not be needed to secure a backbone supply system (from fire main system's point-of-view).

In the new concept the backbone system would be slightly modified, as three fire pumps would serve a lower horizontal pipe, situated at a lower trailer deck. This pipe would serve a higher horizontal pipe, below the passenger and crew departments on RoRo deck, via three riser lines. This concept resembles the reference system without the trunks and isolation valves between valve centers. According to the new rules, these pipes (pipes passing through but not serving) can be built as fire resistant if the pipes: do not carry any flammable liquids, are of substantial thickness or “A-60” insulated, are joined by welding, and are adequately supported [10].

The distribution network would consist of three modular types: crew and passenger departments, cargo areas and watertight compartments. The upper crew and passenger departments could be served by a single riser line and isolation valve per main fire zone. Each main fire zone would have one riser line which would have a connection to each deck level. One horizontal line per deck would branch according to the amount of spaces, and serve the fire hydrants. Each hydrant would have at least a pair of hydrants for back-up – one from a space in the same fire zone (if needed) and one in the adjacent main fire zone. The width of one main fire zone should not exceed 48 meters [6]. Main fire zones widths from 40 to 48 meters allow the use of standard fire hoses from adjacent main fire zones. In case of a fire situation at the crew and passenger area, after the fire has been extinguished, the whole crew and passenger section of the main fire zone in question is isolated – if the fire main system is damaged. However, the intact spaces of this fire zone can be served from fire hydrants of the adjacent main fire zones. The basic concept is shown in figure 6.6.

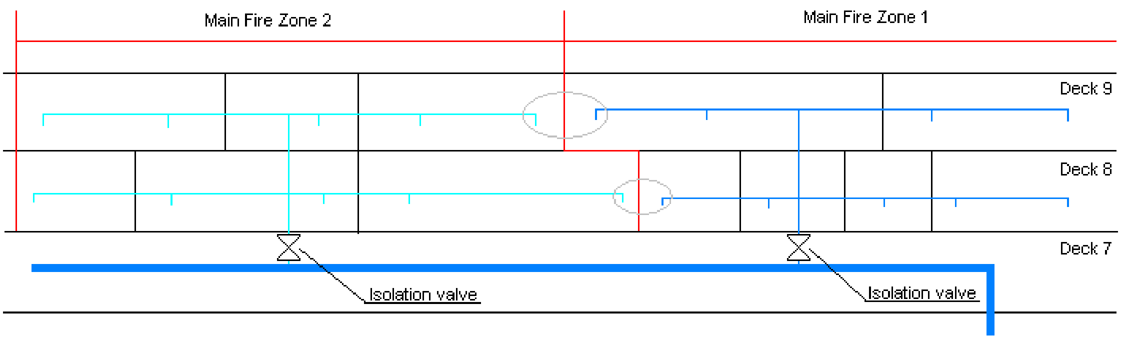

Figure 6.6. *Fire main system SRtP concept – crew and passenger departments.*

The hydrant pairing is shown with grey circles. With standard hose lengths, the back-up hydrant can serve multiple spaces inside the sealed main fire zone. Location of the isolation valves must be decided individually or placed on the RoRo deck (valve survivability is discussed further in the next paragraph).

The cargo areas stretch horizontally across the ship and an entire cargo deck forms a SRtP entity. The hydrants serving the deck must be doubled with both sides of the deck served by a single hydrant. Hydrants must be placed at fore, middle and after part of the ship, depending on regulations and Class demands. In the new design each deck would have a specific vertical pipe line (or more, based on the pressure and flow calculations) from either horizontal backbone line - bearing in mind that the deck containing the upper horizontal line must be served from the lower line and vice versa (decks containing the backbone lines cannot be served from the same deck). The vertical line(s) would feed a horizontal line serving the specific deck and hydrants. As the horizontal line feeds hydrants on both sides at the fore, middle and after part of the deck, the entire SRtP space is secured. This concept is shown in figure 6.7. The cargo decks are also equipped with drencher system, containing fire from spreading to adjacent spaces (according to the interpretations). In case of a fire casualty, each deck can be isolated from the horizontal line's section valve. This is acceptable due to the deck being part of a single SRtP space.

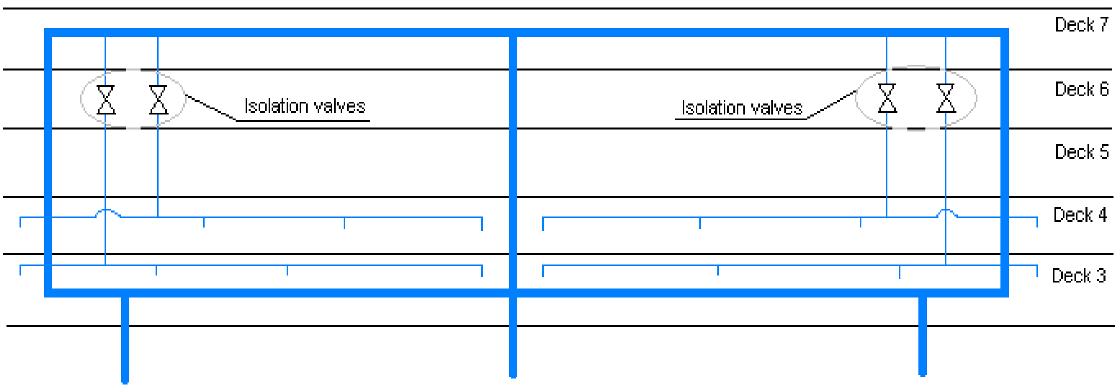

Figure 6.7. *Fire main system SRtP concept – cargo areas.*

The watertight compartments are the most difficult to protect with fire main system, following the SRtP interpretations. As the compartments need to be watertight, no horizontal bulkhead inlets are allowed from adjacent compartments which rules out the concept used in crew and passenger areas. The protection for spaces below deck 3 should be designed specifically for each vessel. There are few basic designs which could be used as a basic solution. First is to use the riser lines from spaces holding the fire main pumps. These lines could serve each deck in that watertight compartment. Secondly, each watertight compartment would be fed by vertical lines from the lower horizontal backbone line (depending on the ship's layout design, a separate line for each deck could be needed). All of the spaces would be served from these lines. According to SOLAS, vertical pipe lines from cargo areas to watertight compartments must be provided with an option for isolation at space in non-watertight area [6]. As a watertight compartment can contain multiple spaces and no possibility for back-up hydrant from adjacent main fire zone, a single isolation valve solution is not possible. This leads to the use of multiple isolation valves, according to each ship's individual layout.

6.6 Sprinkler system

During the analysis of the sprinkler system, it was noted that the system is in accordance with both system and user requirements. However, from an operator's point-of-view the usability of the system can be deemed average. Even greater influence for the need of new designs is the production costs of the system. Most of the additional costs are caused by SRtP regulations - two reasons in particular: the amount of dedicated sprinkler sections, determined by regulations; and three "A-60" rated trunks, needed to protect the section valves.

The “A-60” rated trunks are installed to protect the sprinkler section valves. The trunks in the reference vessel also contain section valves and piping for fire main system. As the trunks are considered spaces of negligible fire risk, the section valves remain operational in all casualty cases. All three trunks extend between decks 5 and 7, and are barely spacious enough for one person to operate all the needed manual actions. These structures cause considerable increase in the system’s production costs. Due to the high costs and optimized space for cargo, the trunks have been made as confined as possible. This leads to complicated valve layout, markings and usability.

Other reason for causing high production costs is the amount of sprinkler sections. This influences directly to the amount of pipes and valves which enable the isolation of each individual section. The Fire Safety Systems code states that the section should not contain more than 200 sprinklers, should not serve more than two deck levels and should not be situated in more than one main vertical fire zone [26]. However, interpretation 30 of the SRtP regulations determines that the section should not serve more than one deck level inside a main vertical fire zone (except stairway enclosures which can be protected by the same section) [10]. As the amount of sections is already minimized to the amount allowed by the rules, savings and/or user-friendly solutions must be searched from the design concept of the pipe network and trunks. The concept for fire main could be fulfilled without the use of the trunks, consequently a new sprinkler design could eliminate the need of trunks completely. One realizable solution is a modification of a concept already designed in the STX Finland AS (Turku shipyard).

Sprinkler system in the reference vessel protects all spaces (considered to need protection against fire) except machinery spaces (CO2 fire-extinguishing system) and cargo areas (drencher system). The design principle in Turku uses the stairway enclosures for vertical riser lines, instead of specified trunks. This design feature could be used to replace the concrete trunks with so called “virtual trunks”. The riser lines passing through stairways would be supplied by a horizontal supply line, on deck 3 for example, which is connected to the sprinkler pump unit (in low pressure systems) or multiple sprinkler pumps (in high pressure systems). Pump(s) lines must have an isolation valve in case of pump failures. The sprinkler system must have a secured connection to the fire main system, according to Fire Safety Systems rules, ensuring water supply in emergency situations [26].

As the pump supply lines for the horizontal supply line are arranged, and the three vertical riser lines are provided in each main stairway enclosure, the design must overcome a problem related to section isolation. This could be carried out by feeding each section with an individual supply line. The stairways themselves must be supplied from another stairway, to provide an opportunity for securely isolating the stairway section. The supply lines are equipped with isolation and indication valves, both located at the stairway enclosure. As the sections are formed by deck levels, the arrangement resembles a tree-like formation. A simplified model is shown in figure 6.8.

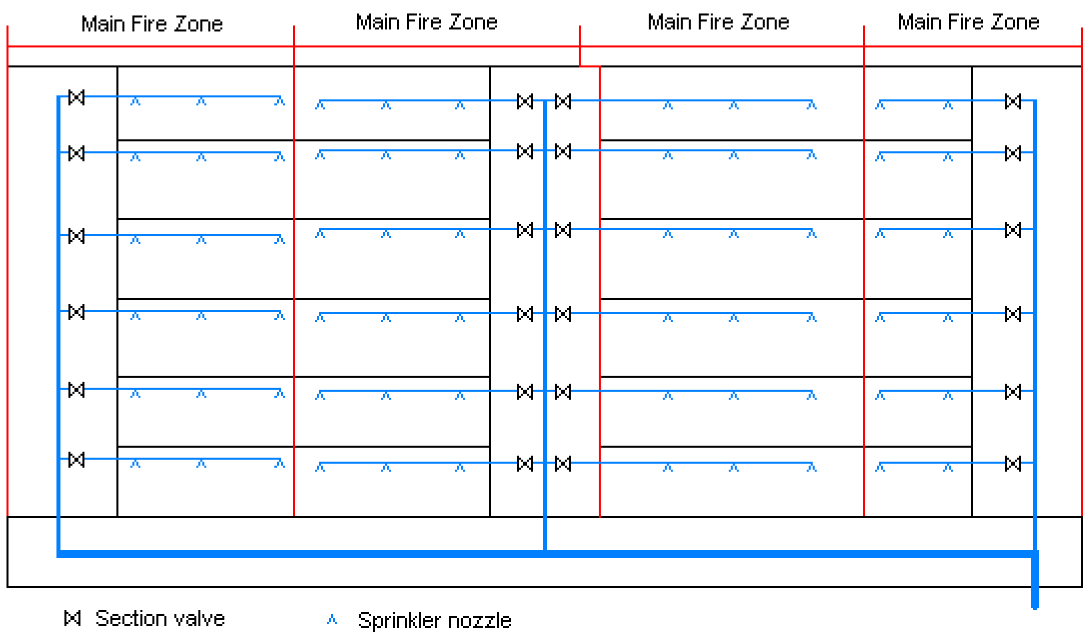

Figure 6.8. *Sprinkler system SRtP concept.*

However, one issue remains which could increase costs unless it is resolved with the Class. If section valves are placed in a stairway (without added protection) and it is considered to be lost in a fire situation, how will it affect the valves? If a stairway is caught on fire, only one section valve needs to be operated after the fire has been put out (isolating the section formed by the stairway which is lost). The rest of the sections do not require any actions. This means that the operability of the section valves could be lost (it retains its current state) but not the valve itself. That is to say, the valve and its joints cannot leak and lower the system pressure. This would lead to a conclusion that the intact sprinkler sections would not be fully operational and could be avoided, with the approval of the Class, if the valves would be designed fire proof (tested accordingly) and the joints should be welded according to ISO 19921: 2005(E) and ISO 19922: 2005(E) standards [10]. In case Class will not approve this type of arrangement, each valve should be protected with "A-60" rated casings with internal water nozzles.

If Class approves the survival of fire proof valves (not their operability), remote controlled features for valve operations could be considered. A valve control cabinet located at each stairway would control electro-hydraulic closing valves. The control cabinets would be redundantly connected to IAS and supplied from both main- and emergency switchboards with an automatic changeover. In all SRtP scenarios the valves inside the stairway enclosure could be remote controlled, except when the stairway itself would be lost. In this case, the valves do not need to be operated (except the stairway's section valve which would be located in another stairway, from where the section is supplied).

6.7 Bilge system

The SRtP concept for bilge system can be deemed troublesome for ship's operators. The operations for isolation of spaces (bilge main pipeline) and the use bilge pumps are handled manually (in SRtP scenarios). The suction line valves are operated from IAS or locally in malfunction situations.

Bilge pumps can be operated via IAS but in SRtP scenarios, the use of the pumps are instructed to be operated manually. This requires additional personnel, as well as good communications between the coordinator and the persons managing the pumps. In general, accessing the bilge pumps and operating them manually is relatively easy. This is however not the case with all of the isolation valves. There are three types of isolation valves, all except one operated manually. The first, and most common type, is a normal butterfly valve operated locally beside the valve. Some of the valves are placed in places which are hard to locate and access, even with sufficient markings. The second type of valve is a manually remote controlled valve (butterfly), where the actual valve and its operating location are not in the same space. These valves are operated with a fixed hand wheel connected to the valve with an extension. The third type of valve is also connected to the valve with an extension but operated with a special tool, located next to the valves. These operating places are located at cargo areas and, even if carefully marked, the access could be restricted due to cargo loads. The bilge suction line valves are electro-hydraulic non-returning valves with manual operation possibility in malfunction situations.

The bilge system's SRtP concept can be enhanced with slight modifications. The arrangement for bilge pumps should remain as presented in the reference vessel, at least two bilge pumps serving the whole ship. These pumps should be located at the fore and after parts of the ship, connected with bilge mainline. Usually the after bilge pump must be placed higher than the bilge mainline due to the shaft lines and the ship's form. Extra attention should be given in these cases to ensure that the suction power is sufficient for the whole length of the bilge line.

The bilge pump operations in SRtP have been instructed to be done manually to avoid unnecessary analyzing work during the design phase. This could be avoided with few modifications and due to the new interpretations. In the reference system the bilge pumps have a doubled power supply with manual changeover beside the pump. This can be changed to automatic changeover, without adding too much cost. New interpretations allow the use and survival of fire-resistant cables, (complying with standards IEC 60331-1 and IEC 60331-2 [10]) passing but not serving the spaces, in fire casualty scenarios, and the survival of cables (passing but serving) in flooding scenarios. This enables the possibility of a concept where pumps are operated from IAS. If the control cables are doubled from separate IAS cabinets, the bilge pumps can be controlled from IAS in every SRtP scenario. However, to avoid additional costs single control cables can be used, provided that the pumps have a local control possibility in cases where the IAS cabinet itself is lost.

The isolation valves for bilge mainline can be brought under normal valve control system with few modifications. The valves should be electro-hydraulic butterfly valves, connected to a valve control cabinet. The cables should be of fire resistant material and the routing of control cables should be designed in a way that the cable is only in the same space with the bilge mainline when connected to the valve itself. This means that the valve control cabinet should be placed higher than the watertight compartments, and that the cables are routed to the spaces vertically above the served space (whenever it is possible). This enables the remote use of isolation valves in all SRtP scenarios where the bilge isolation valves must be used. In case of a casualty concerning the valve control cabinet, the bilge mainline and isolation valves remain in normal operation condition (that is to say, do not require any actions). However, for further redundancy, all of the valves can be operated locally with either a portable pump(s) or with specific tools.

The suction line valves control can be executed with the same concept used with the isolation valves. Portable pump(s) is provided for redundancy. However, using local control in void spaces may not be allowed depending on the class society. Access to void spaces with bilge suction should be arranged via watertight hatches instead of bolt hatches, if the use of portable pump is allowed. In cases where the local operation is not allowed, other designs must be considered.

Bilge level switches are examined in the next paragraph.

6.8 Flooding system

The current flooding system concept is based on duplicated sensors where one is connected to IAS and the other to flooding alarm panel at the bridge. This design meets all requirements set by regulations but causes unnecessary expenses. With a different designing approach, the system could be built with lower costs yet fulfilling requirements set by operators and regulations.

Instead of using two sensors, individual cables and IAS as a back-up system, the system could be designed much in the same way as the loops in fire detection system - either straight under IAS (if possible from supplier's point-of-view) or under a subsystem. This would require two central units (process stations) located in separate SRtP spaces. Each deck, under the supervision of flooding detection system, would have its own detection loop, equipped with address units, short-circuit isolators and dedicated flooding sensors in each SRtP space. The isolators must be installed in a way that each predetermined SRtP space is automatically isolated from both sides during possible malfunction situations. The central units operate under master/slave principle and are connected to each other via fiber-optic data cable. If one of the loops is damaged, both intact loop segments are supervised by the unit they are attached to. The basic principle of the design is presented in figure 6.9.

The concept is approved by Class in fire detection system and thus could be used in flooding system as well. This design enables the use of only one sensor in all casualty scenarios, and significantly reduces cable costs. Also, additional savings can be acquired if bilge level sensors could be coupled as part of the system. Bilge level switches measure the same value for bilge level alarms but for different purpose. In the reference ship, there are examples where four individual sensors (with dedicated cable connections) measure the same value for different purposes. The change of concept would mean that all the required information could be gathered from a centralized system and passed on where it is needed.

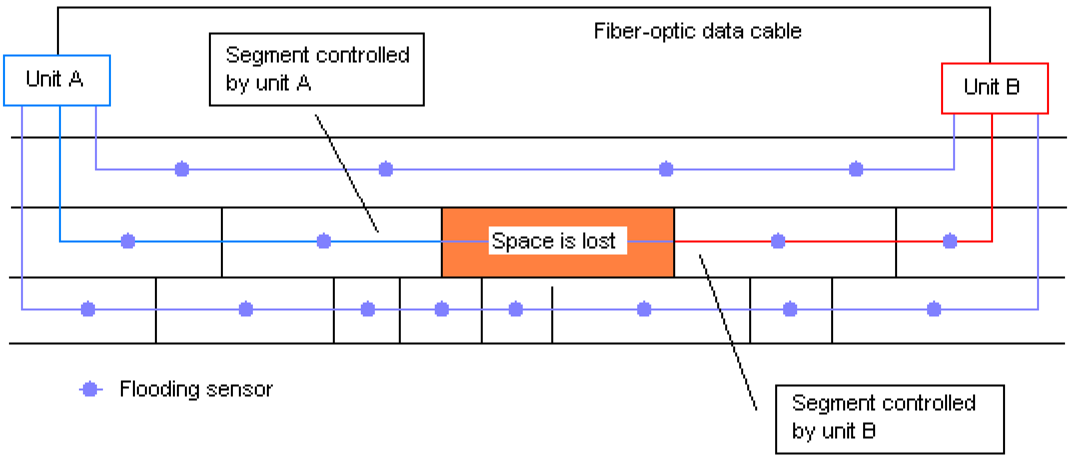

Figure 6.9. *Flooding system SRtP concept.*

The problem however, is the purpose of the alarm. Bilge level alarms are intended to notify personnel to start bilge suction when a compartment has been exposed to water. This is normally measured and indicated by a float switch. The sensor(s) has been installed to react to small amounts of water, for example in bilge wells. Flooding alarms are also measured and indicated by float switches but the sensors are installed to measure substantial water ingress into a watertight compartment. This is normally done by installing the sensors to 0.1-0.2 meters above the lowest point [27]. The flooding sensors are used for common alarms and to notify the load calculation computer about a possible leakage. This information affects the heeling and ballast systems of the ship, as well as stability calculations.

Both bilge level and flooding sensors are normally very simple micro switches. Due to the amount of sensors (135 flooding and bilge sensors in total), more sophisticated versions are not commonly used. If bilge and flooding information would be measured with same the sensors, this could lead to the use of more sophisticated sensors or individual sensors for both purposes, and it would increase total costs of the system. In either case, same design concept can be used. The use of flooding sensors for bilge level indication (and vice-versa) must be approved by the Class.

The savings with the new concept are difficult to estimate, depending on the layout, system supplier and used sensor types. According to Lehtonen, savings become sufficient if the vessel is a normal size car passenger ferry. If the vessel is smaller, yet classified as a passenger ferry, the old concept may be more economical [17]. A concrete estimate of the total costs for both design concepts was conducted, based on the information from the reference ship. The results are presented in table 6.10.

Table 6.10. *Flooding system evaluation.*

Old concept:	Costs:
Flooding panel	322€
14 distribution boxes	700€
24 sensors	2880€
12 IAS connections	4500€
850m of cable (installed)	2975€
System installation and testing	3200€
Total:	14 617€

New concept:	Costs:
2 loop cards	600€
Graphics (Software)	1500€
9 address units	1350€
9 short-circuit isolators	300€
540m of cable (installed)	1890€
System installation and testing	2200€
Total:	7 840€

The costs for the old concept were gathered from the ship's material information. The length of the cable was calculated from drawings and multiplied with an estimate of work costs per meter. The new concept was designed with one control loop handling all flooding sensors. The loop would be part of the existing fire alarm system. An evaluation of the design costs were provided by the system supplier. According to the suppliers, similar concept has been previously approved by the Class. As can be seen from the table, the new concept could drastically reduce system costs. There are three main reasons for the decrease: shorter cable routes, half the amount of sensors and no back-up connections to another system. Also, the centralized information is easier to distribute to another systems. If bilge level switches could be installed as part of the loops, it would lower the overall costs significantly.

6.9 Testing and support

The testing protocol for SRtP related systems is approved by all parties involved: Class, owner and shipyard. The testing is based on a theoretical analysis of each system (overall, detailed assessments and FMEA). Solutions based on routing (pipes, cables) are proven by comparing the actual routes with the routes informed in design diagrams and analysis. Most system features are tested in quay tests when normal system tests are being made. Some tests are carried out in sea trial when it is absolutely necessary.

One improvement related to SRtP testing could be made. The scope of testing is always narrowed to each individual system to avoid unnecessary testing (double testing). However, in most cases the systems are in interaction with each other. Testing should always be specified to test a certain wanted function, instead of concentrating on a single system. If a feature is considered important, and dependent of another system, the test should be carried out so that the operability after the critical feature is proven. This includes all actions related to the feature, not just SRtP actions. As an example from the reference vessel: when the after main engine room is considered lost, it paralyzes the port shaft line. This is due to the loss of port side shaft generators, situated in the after main engine room. To overcome this problem, the shaft generators can be isolated from the power train by dismantling shaft couplings from forward main engine room. During the quay tests of *Spirit of Britain*, the dismantling of the couplings was demonstrated (needed to be done in a preset time) but the operability of the shaft line was not tested after the operation. The main engine automation system prevented the shaft line from working, as the loosing of shaft generators resulted in a group of alarms categorized to prohibit engine start-up. This type of interactions should always be acknowledged and tested. This means that the failure should be modeled as realistically as possible and the testing should focus on operability of the ship/system, not the feature itself.

There was no organized training or support for the personnel of the reference vessel on SRtP related issues. All the training for the ship's personnel has been arranged by the owners, after the ship's delivery based on the materials provided by the shipyard. Additionally, the shipyard system designers are not trained sufficiently for SRtP issues. Both the personnel of the ship and the shipyard designers should be subjected to adequate SRtP training. The system designers should understand the basis of the SRtP approach, as well as the newest interpretations. Most importantly, they should be able to recognize and understand larger entities in SRtP scope. As the regulations and processes for SRtP related systems take shape, interactions and overall view become important. This could also increase the possibility of system designers coming out with new innovative ideas for the related system designs.

Also, the personnel of the ship should be given training and sufficient technical support already during the finishing phase. This could be arranged my mutual coordination between the shipyard and the owners. Both parties would have a SRtP coordinator, in charge of information exchange and coordination (operating procedures, theory and analysis behind each design concept). The shipyard would provide basic materials, argumentation and solutions to the owners already during the design phase. This way, the operators would be aware of the theoretical basis behind each solution. The shipyard would train one or two persons dedicated by the owner, and they would distribute the information onwards to the personnel.

After the systems are installed, the shipyard would provide sufficient training and technical support for each SRtP system. When the ship is to be delivered, the personnel would be familiarized and trained, by the owners and the shipyard, for different emergency scenarios following the owner's operating procedures – already possessing the theoretical and technical knowhow for each system. This would ensure that the operators know how to maintain and use each individual system, and how the ship would act as a single unit in different emergency situations.

7 CONCLUSIONS

The analysis of the SRtP interpretations, procedures and systems showed that the SRtP process (and the concept itself) is still under development. IMO, and its committees, must receive feedback from the field to adjust the regulations and interpretations to match the current needs and economical aspects of the operators and shipyards. This includes the interaction with Rauma shipyard, a feedback channel which the shipyard should try to use and develop. According to the research, the SRtP process used in Rauma shipyard could be further enhanced, especially from a system concept perspective. This includes better understanding of operators' needs, acknowledging ship as a single entity in emergency situations, new cost effective design concepts and developing of testing & support practicalities. Developing the whole SRtP process ensures the best possible system concepts for each ship, and guarantees that the ship is prepared for all possible emergency situations.

7.1 Regulations and interpretations

During the development process it was found out that some of the regulations and interpretations received from IMO could be enhanced to be more realistic and more sufficient to the demands of the industry. These two main issues were determining spaces of fire origins and enabling the use of electrical control signals in spaces with negligible fire risk. Both issues need development before they can be approved by IMO. However, the shipyard should develop solution proposals for these issues and present them in the IMO's SRtP development group, STX Finland AS (Rauma) being part of (with Finnish authorities) the group. When possible modifications are proposed, the shipyard should see to that its own process follows the instructions from IMO (for example, cross-reference between fire & flooding scenarios, and fire & flooding sensor layout).

7.2 Operating procedures

SRtP regulations are set to ensure sufficient measures for prevention and readiness of emergency situations. However, during the analyzing phase it became clear that there is no consensus for operating procedures if this type of events occurs. Prevention of emergency situations of occurring and the sustainability of the ship in these conditions are measures which reduce the probability of an emergency but do not eliminate it completely. Guidelines for operating procedures of a ship in emergency situations should be decided during basic design phase, in cooperation with the owner (such as the use of Safe Areas and SRtP system features). When the procedures are known prior to the design phase, the systems can be developed further - for example, to assist in decision making, coordination and control. The approach allows the ship and personnel to work as an entity, improving the possibilities in emergency situations, and guarantying that the ship (and the personnel) is prepared for all kind of emergency situations.

7.2.1 Safety Center, IAS and data LAN

All car passenger ferries equipped with a standard Safety Center should be upgraded to a complete and redundant Safety Center concept. This requires a SOSE approach for the systems from the beginning of the design phase but brings out features beyond any single system. From Safety Centers, all needed systems could be monitored and controlled (fire and flooding detection, and CCTV cameras acting as the basis for decision making). Safety Centers would also contain all needed communication and alarm equipment. Also, if automation and/or remote control are considered in SRtP scenarios, a HMI for different systems would be provided. As a basic concept for future vessels, this thesis considers the following changes and/or additions:

- Two Safety Centers located in different main fire zones
- More sophisticated and distributed process stations and/or RTUs for IAS
- A logical two way ring (or a hybrid topology) topology used between RTUs, process- and operating stations when possible, and when all other system requirements are met
- System integration coordination by shipyard

More sophisticated RTUs would increase options for different layout solutions in SRtP sense. Using a two way ring topology, whenever possible, would automatically guarantee redundancy in all cable or station failure situations. If a ring topology is not possible, or beneficial for some other reason, a redundant hybrid topology should be considered Power supplies to IAS cabinets should continue to be provided by two UPS system – securing power supply in all situations..

Data LAN and Safety Center concept requires good system integration between different systems. This can only be done with good coordination by the shipyard. As the operating procedures and emergency concepts are known prior to basic design phase, the system suppliers can be informed about requirements placed on interoperability.

7.3 SRtP systems

Based on the reference vessel, some SRtP system concepts could be updated. Furthermore, the concepts require modularity as each ship is different with different requirements and build. Yet, each system should fulfill requirements set by the regulations. The analysis showed that propulsion-, fuel oil-, fire main-, sprinkler-, bilge- and flooding systems could be improved with new design concepts. These concepts could lower the costs and/or improve the usability of the system from operator’s point-of-view. Some designs require the approval of Class, some the clearing up of future regulations. As the whole SRtP process evolves, the shipyard should try to stay one step ahead to be able to provide secure and cost-effective SRtP system designs.

7.4 Testing and support

Testing of SRtP related features is arranged well in Rauma shipyard. Most of the SRtP situations are managed with different cable and pipe routing which is proven without separate testing (during sale inspections). Each system and SRtP feature is tested during either quay or sea trial. However, testing should be improved by focusing more on why the feature is used instead of testing the feature itself. That is to say, the test should include the actual testing of the action/feature but it should also prove that it enables wanted system/feature operability. This could include interconnected systems beyond SRtP scope.

Technical support is sufficiently provided during building phase and with warranty after delivery. However, support and training for systems and situations is not sufficient – both for the operators and for system designers. The system designers should be trained to fully understand the SRtP concept and the current interpretations. Main focus should be shifted from system oriented approach to system of systems based thinking. For this, internal training is needed. Also, training for the operators should be provided: First, by distributing the theoretical information through a contact person. Second, providing system and scenario based training for the operators. This would secure the safe use of each system, as well as the personnel being part of the ship's larger emergency capability. Also, this would add the shipyards knowhow on how personnel want and must use certain systems/features in different emergency scenarios.

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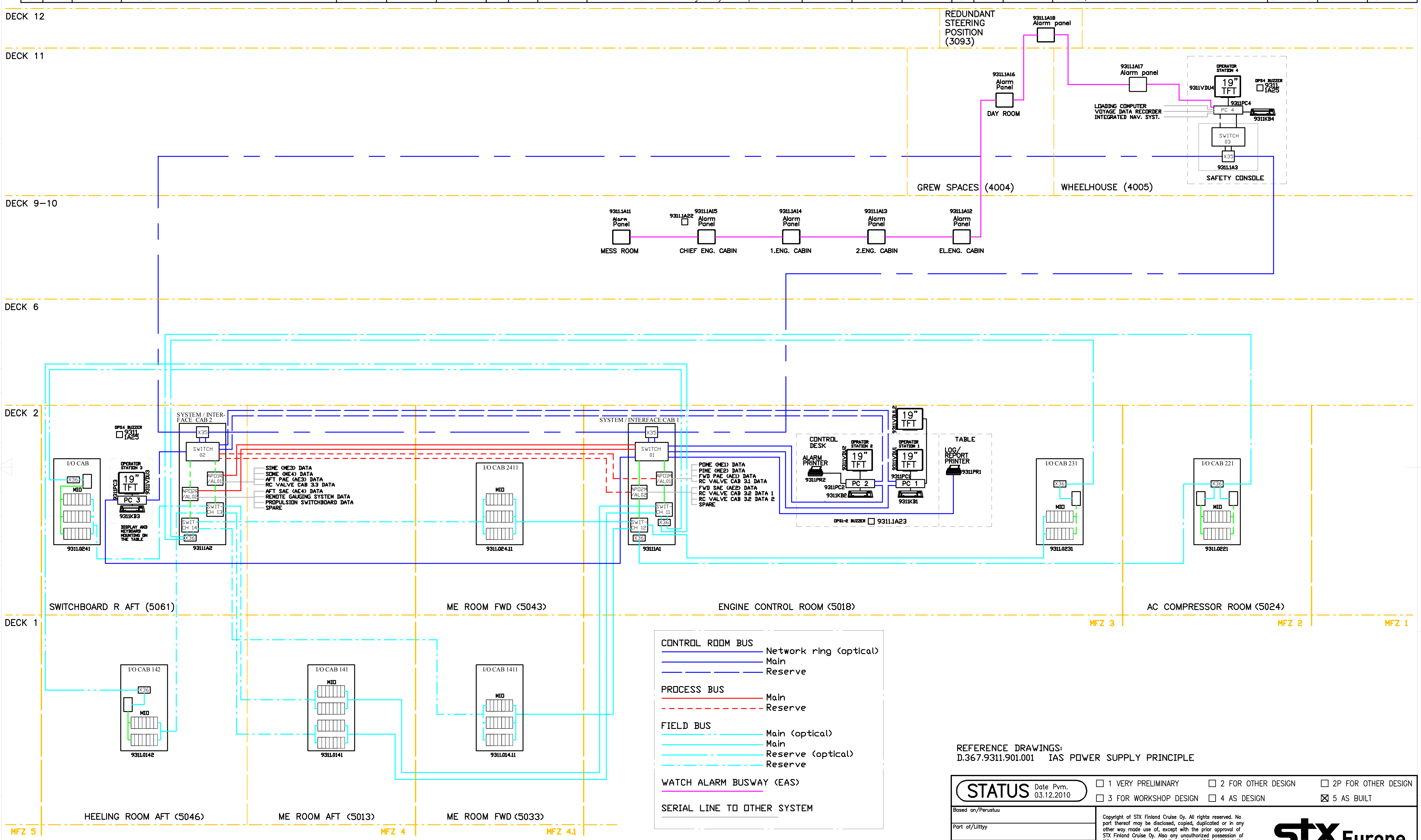
APPENDICES:

Rev. Versio	Part no. Osanro	Field Kenttä	Alteration or remark Muutos tai huomautus	Date Pvm.	Changed by Muuttaja	Approved by Hyväksyjä
D			AS BUILT	2010-12-03	HSO	PLH
C			Added OPS buzzers and changed Day room panel location	2009-10-02	HSO	PLH
B			UPDATED, ACCORDING TO VALMARINE IAS	2009-05-27	HSO	PLH



CONTROL ROOM BUS
- Network ring (optical)
- Main
- Reserve

PROCESS BUS
- Main
- Reserve

FIELD BUS
- Main (optical)
- Main
- Reserve (optical)
- Reserve

WATCH ALARM BUSWAY (EAS)

SERIAL LINE TO OTHER SYSTEM

Integrated Alarm, Monitoring and Control System (IAS)

Capacity (as built):
- 3022 I/O points
- hardwire spare channels (without software and cabling) is abt. 450pcs
- additionally over 10% empty space for hardwirwe I/O's in I/O cabinet
- 45 customised Mimic diagrams.

Interfaces to other systems:
- Integrated Navication System
- Voyage Data Recorder
- Remote Gauging System
- Loading Computer
- Remote Controlled Valves Unit (3)
- Main Engine (4)
- Diesel generator (4)
- Propulsion Switchboard.

Following functions are to be carried out:
- alarm, monitoring and control loops (machinery systems, as bilge, ballast)
- Main Engine monitoring
- Power Management System
- pumps remote control (specificity separately):
  - ✱ st-by control
  - ✱ blackout start
- valves remote control
- engine rooms fans remote control
- FO viscosity remote control
- tank level and draft gauging.

REFERENCE DRAWINGS:
D.367.9311.901.001 IAS POWER SUPPLY PRINCIPLE

STATUS Date Pvm. 03.12.2010

☐ 1 VERY PRELIMINARY ☐ 2 FOR OTHER DESIGN ☐ 2P FOR OTHER DESIGN
☐ 3 FOR WORKSHOP DESIGN ☐ 4 AS DESIGN ☒ 5 AS BUILT

Based on/Perustuu

Part of/Liittyy

Replaces/Korvaa

stx Europe

Design. Suunn. HSO	Tel. Puh. 4276	Dpt. Osasto 213	Date Pvm. 2009-01-13
Check. Tark. PLH	Tel. Puh. 4266	Dpt. Osasto 213	Date Pvm. 2009-01-13
Appr. Hyv. MPA	Tel. Puh. 4200	Dpt. Osasto 213	Date Pvm. 2009-01-13

Title/Nimitys

P&O RoPax Ferry, NBs-1367 and - 1368
INTEGRATED AUTOMATION SYSTEM DIAGRAM

IMO NUMBERS: NB1367=9524231, NB1368=9533816

Program/Ohjelma AutoCAD | Paper size/Arkkikoko A3 (297x420) | Mass Massa | Scale Mittak. 1:1

Drawing number/Piirustusnumero D.367.9311.901.002 | Rev./Ver. D | Page/Lehti (Pages/Lehtiä) 1(1)

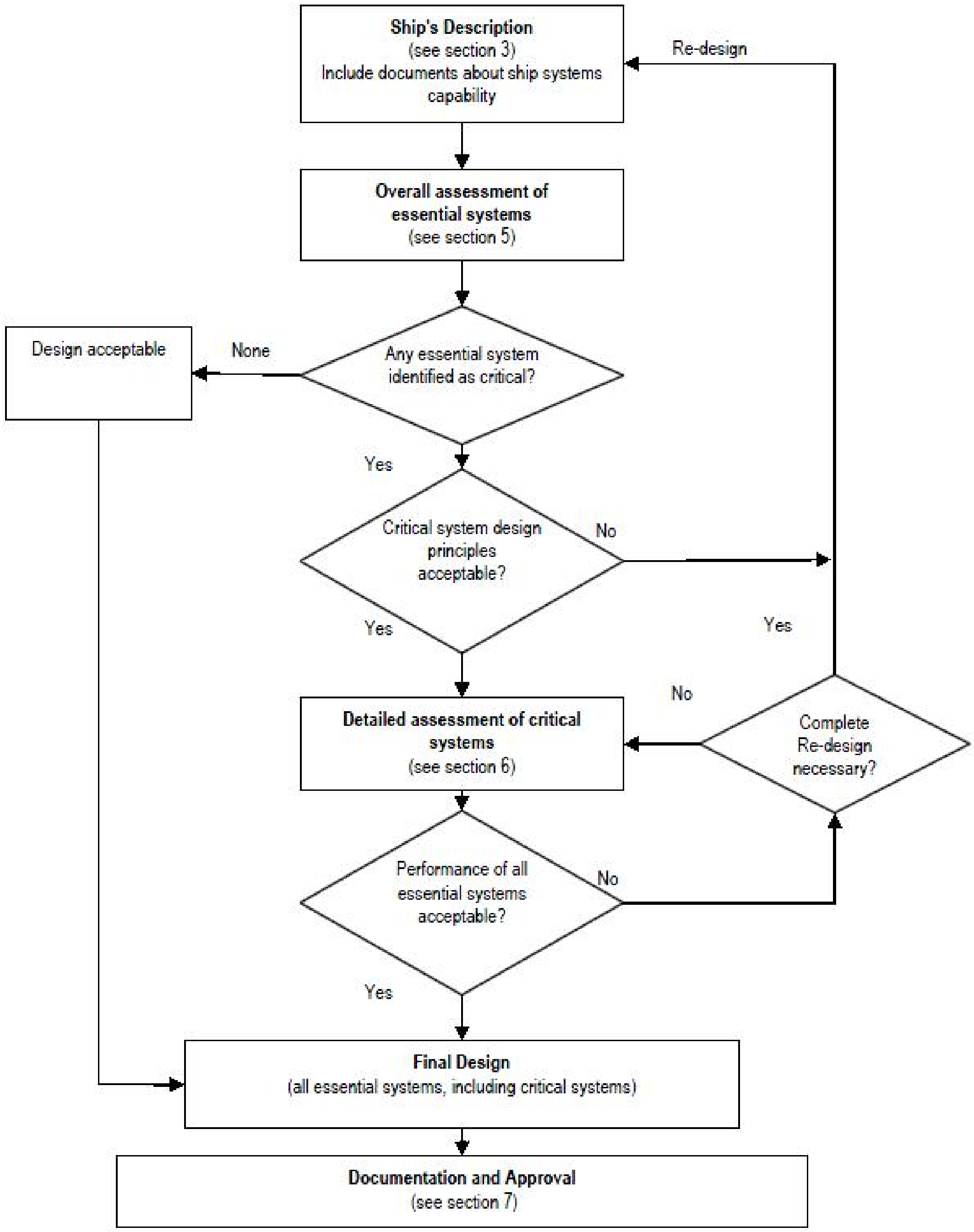
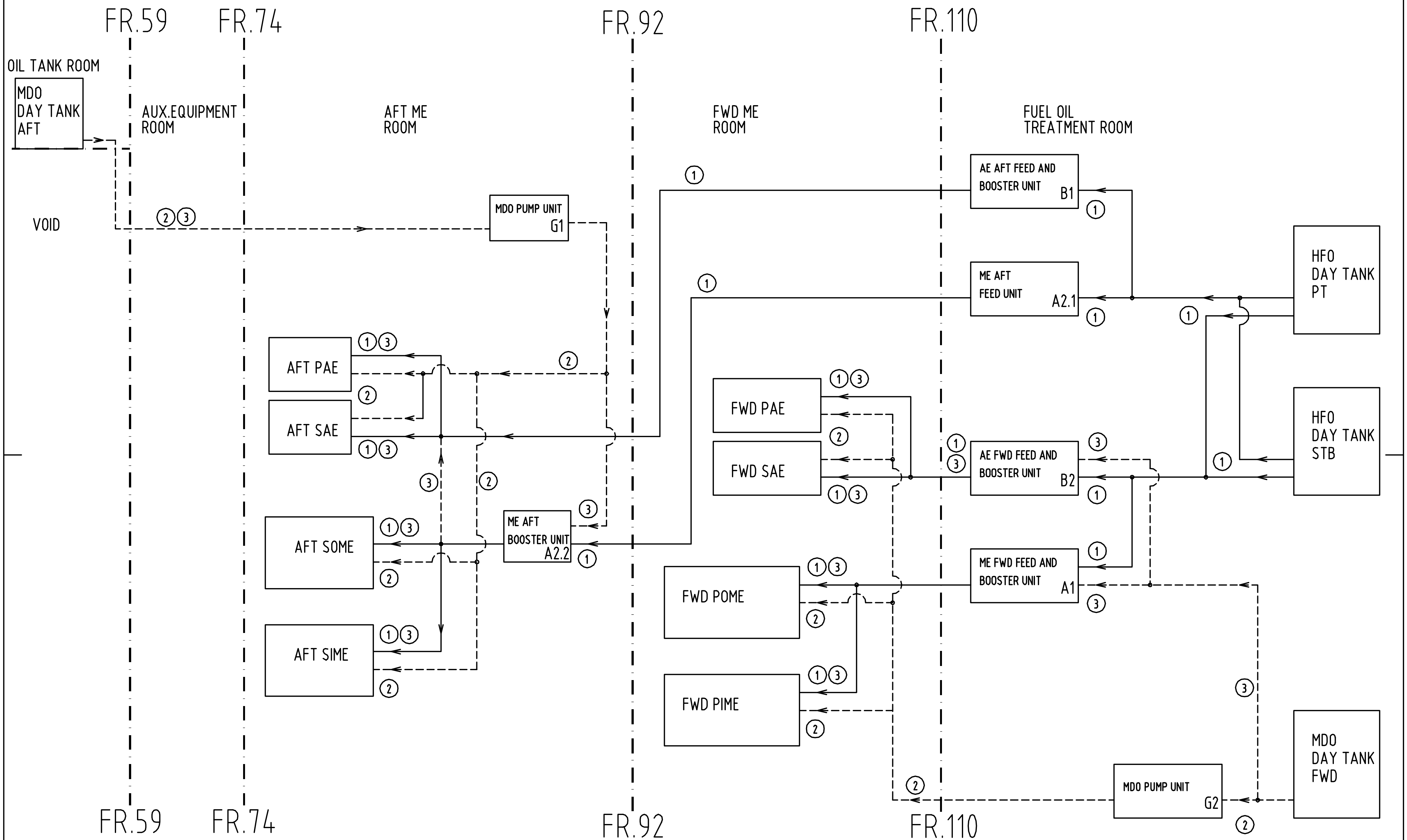


Figure 2.2. *Assessment of passenger ship systems' capabilities process flowchart [9].*



1 Normal running mode with HFO

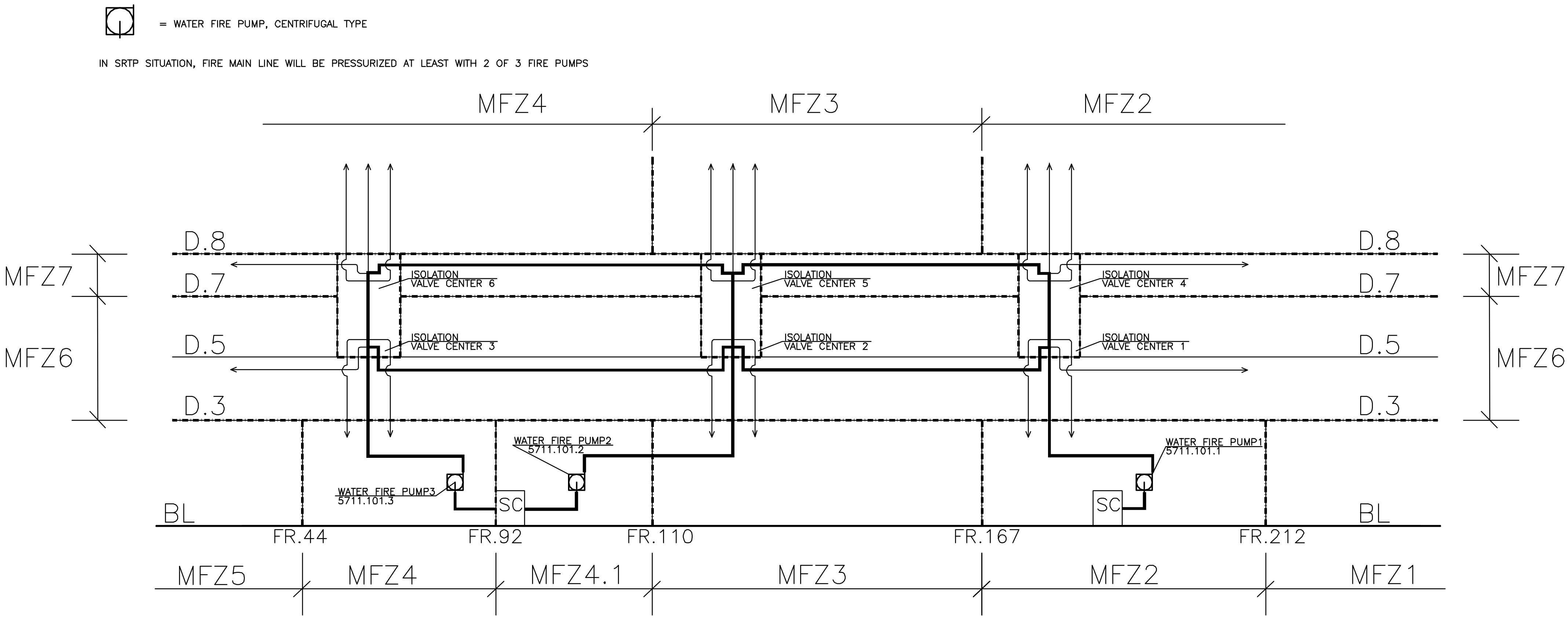
2 Black out / emergency mode with MDO

3 Safe return to port mode with MDO

Principle of fuel oil supply system

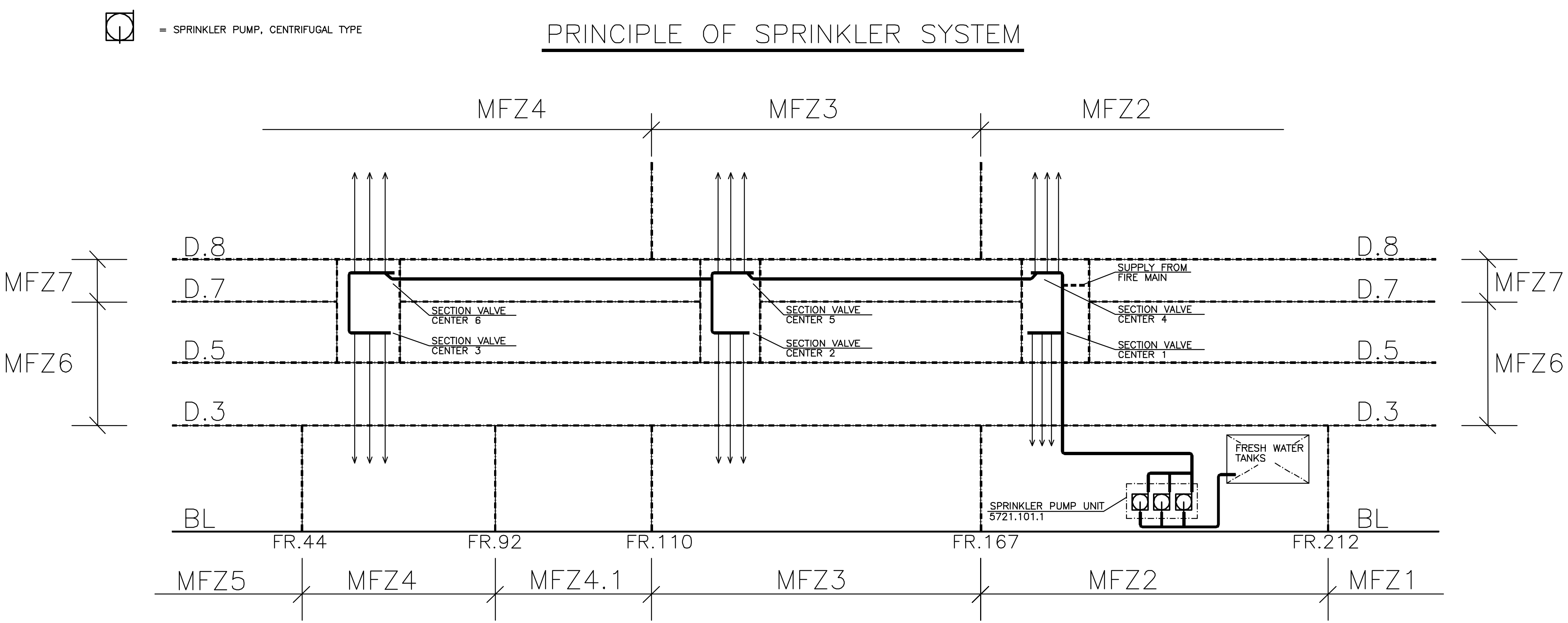
version	1	Appendix 1	STX Finland Oy
date	24.09.2009	Figure 104-1	RoPax Ferry, NBs-1367 and -1368
signat.	T.Waltari		

PRINCIPLE OF FIRE MAIN RING LINE

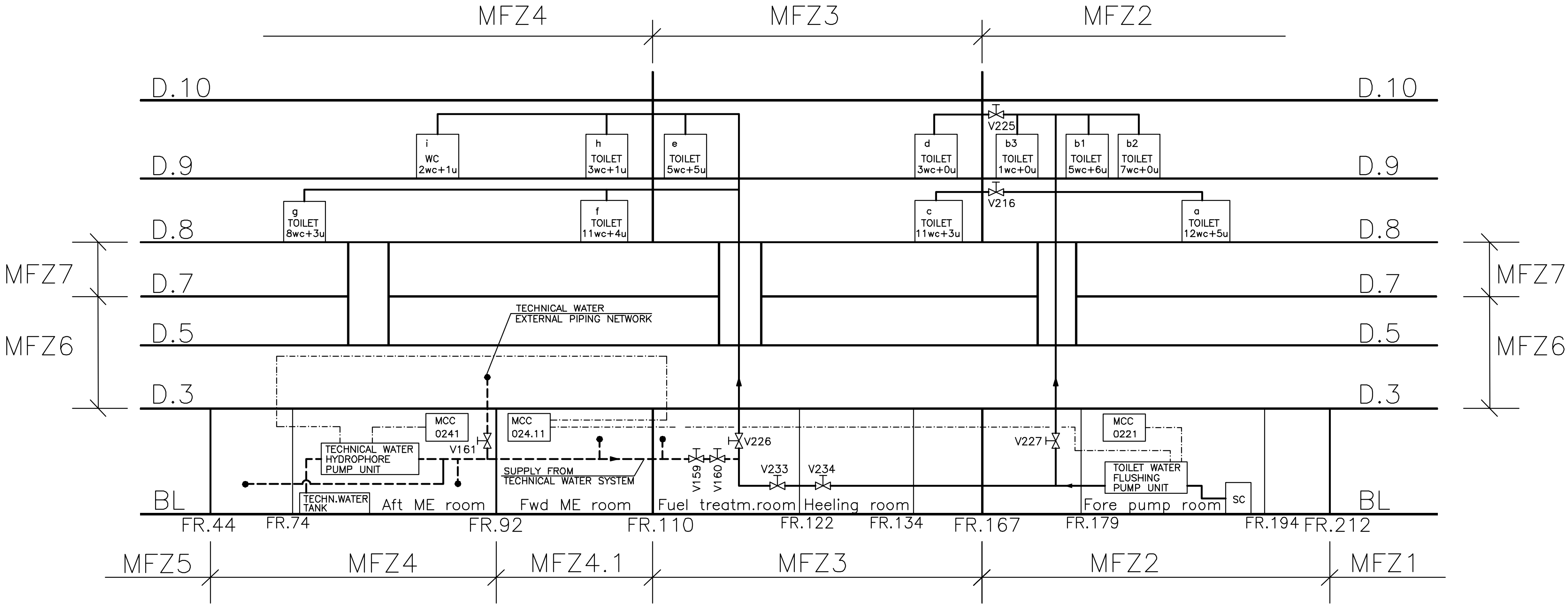


APPENDIX 1
Figure 107–1

Version date:
30–Nov–2010



APPENDIX 1 Version date:
Figure 108–31 03–Sep–2009



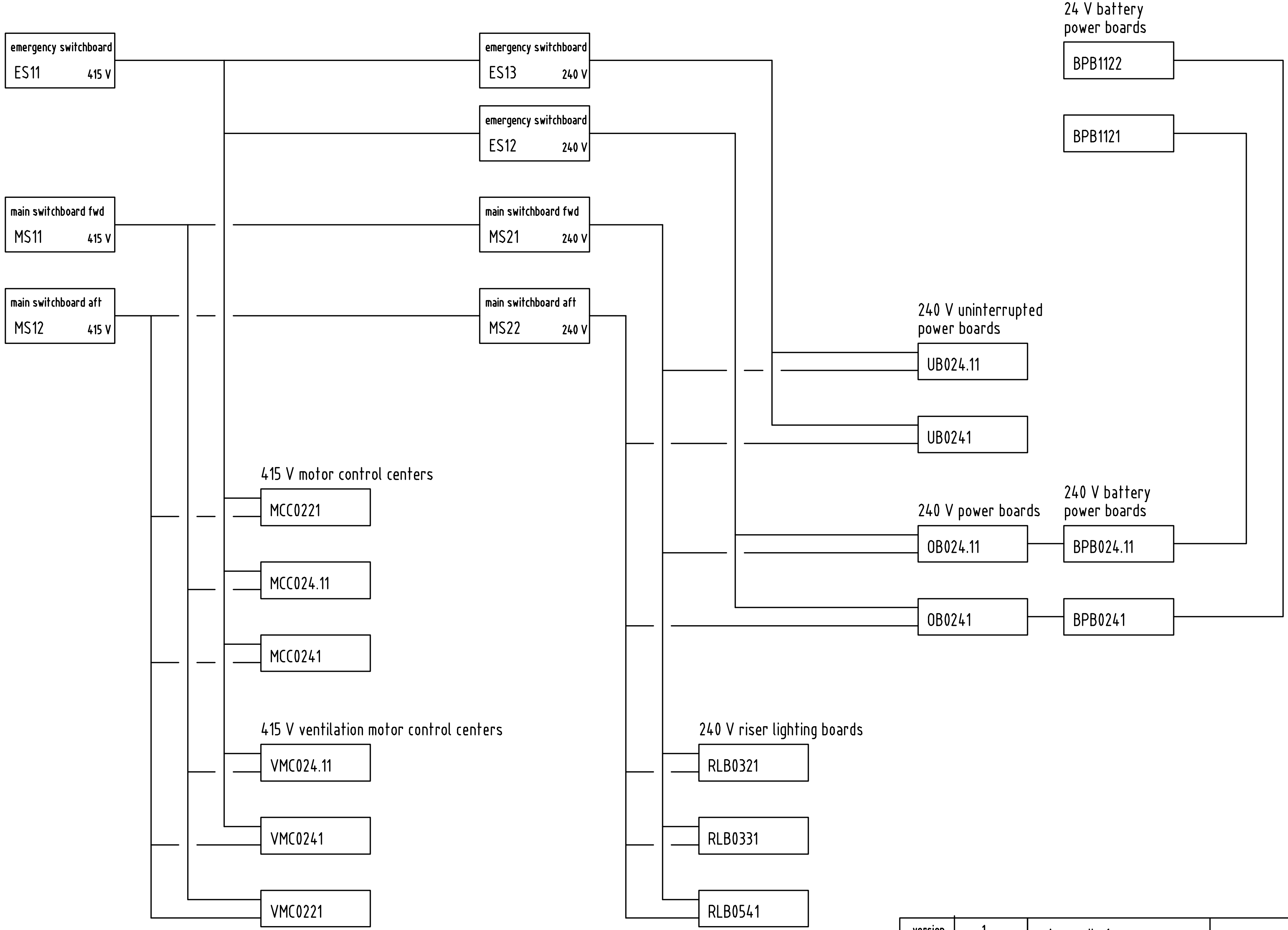
PRINCIPLE OF GRAVITY WC SEA WATER FLUSHING SYSTEM

MCC0221 FWD motor control central (MS12)
MCC0241 AFT motor control central (MS12–ES11)
MCC024.11 FWD motor control central (MS11–ES11)
SC Sea Chest

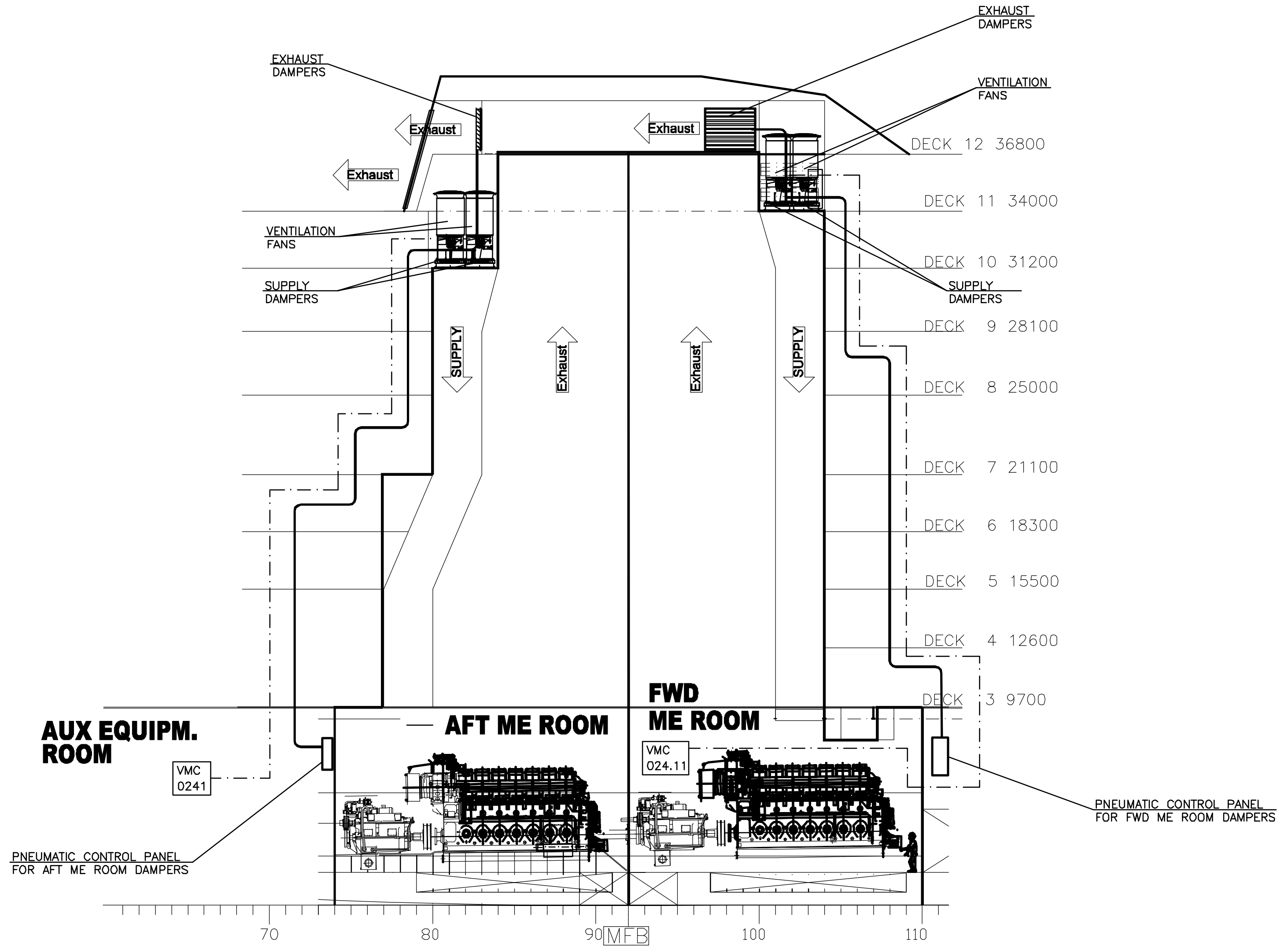
- - -▶- - - Pipe routing, technical water
——▶—— Pipe routing, sea water
–·–·–·– Cable routing

Version date: 23–Dec–2009

APPENDIX 1
Fig. 112–100



version	1	Appendix 1	STX Finland Cruise Oy
date	15.06.2009	Figure 121-2	RoPax Ferry, NBs-1367 and -1368
signat.	LB-DMH		



PRINCIPLE OF FWD AND AFT ME ROOM VENTILATION

VMC024.11 AFT VENTILATION MOTOR CONTROL
VMC0241 FWD VENTILATION MOTOR CONTROL
——— PIPE ROUTING
—·—·— CABLE ROUTING

Version date:
28-Nov-2009

APPENDIX 1
Fig. 101–114